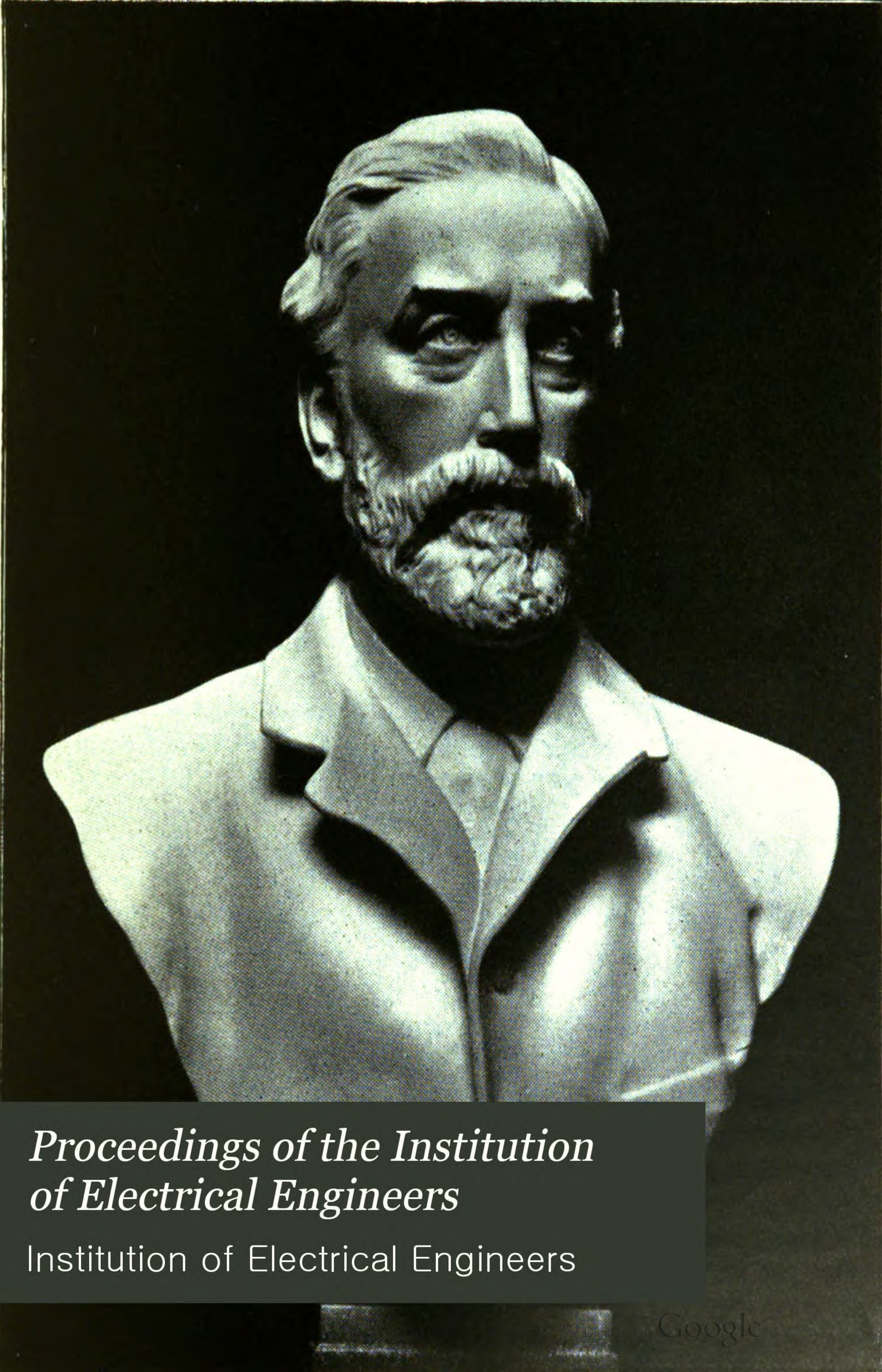

Proceedings of the Institution of Electrical Engineers

Institution of Electrical Engineers

LELAND·STANFORD·JVNIOR·VNIVERSITY

JOURNAL

OF THE

INSTITUTION OF ELECTRICAL ENGINEERS,

ORIGINALLY

THE SOCIETY OF TELEGRAPH ENGINEERS.

FOUNDED 1871. INCORPORATED 1883.

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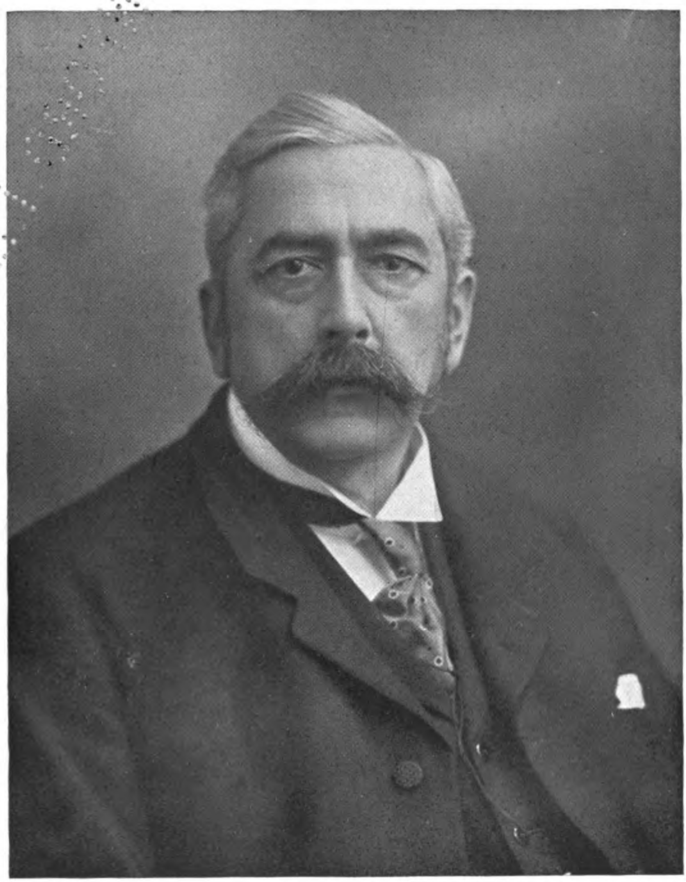

Gisbert Kapp

PRESIDENT 1909-10

The Institution of Electrical Engineers.

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JOURNAL

OF THE

Institution of Electrical Engineers.

Founded 1871. *Incorporated* 1883.

VOL. 44. 1910. NO. 199.

Proceedings of the Four Hundred and Ninety-sixth Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, November 11, 1909—Mr. W. M. MORDEY, President, in the chair.

The minutes of the Ordinary General Meeting held on May 13, 1909, were taken as read, and confirmed.

Donations to the *Library* were announced as having been received since the last meeting from W. P. Adams, P. R. Allen, C. J. Beaver, Dr. K. Birkeland, J. H. Briggs, F. Broadbent, Congrès International des Applications de l'Électricité, W. Cramp and C. F. Smith, U. Crudeli, P. Dawson, G. H. Elliot, Engineering Standards Committee, Dr. J. A. Fleming, B. Gati, E. Giebe, C. C. Hawkins, Messrs. Harper Bros., W. B. Hird, H. M. Hobart, Messrs. Ulrico Hoepli, A. Home-Morton, International Electrotechnical Commission, Professor A. Jamieson, Dr. A. E. Kennelly, Königliche Technische Hochschule, Danzig, W. R. Kelsey, F. Kohlrausch, A. W. Marshall, A. Marson, Major W. A. J. O'Meara, Comptroller of the Patent Office, Physikalisch-Technische Reichsanstalt, Messrs. S. Rentell & Co., Ltd., Dr. E. Rosenberg, The Royal Society, H. Sherley-Price, C. F. Smith, J. A. Smith, Messrs. E. & F. N. Spon, F. H. Taylor, A. V. Thomas,

Dr. S. P. Thompson, W. N. Twelvetrees, the University of Illinois, Messrs. Vuibert et Nony, F. Wallis, L. H. Walter, Secretary of the War Office, W. D. Weaver, and H. Wilde; to the *Building Fund* from F. W. Clements, J. H. Garratt, T. D. Lockwood, E. Mercer, and A. H. Unwin; and to the *Benevolent Fund* from the Electrical Engineers' Ball Committee, M. Heaphy, W. Routledge, A. M. Taylor, and the Twenty-Five Club, to whom the thanks of the meeting were duly accorded.

The PRESIDENT (Mr. Mordey) then presented the premiums and scholarships referred to in the Annual Report for the year 1908–9.

Professor BERTRAM HOPKINSON: I rise, sir, on behalf of my mother, to ask you to accept for the Institution of Electrical Engineers a memorial bust of my father, Dr. John Hopkinson. In doing so I do not intend to attempt any appreciation of my father's work. Among this audience are present most of those who are best qualified to form an opinion upon that point, and it would be presumptuous in me, even if it were fitting for his son to undertake the task, to express my views upon such a matter. But I think I may endeavour to indicate the reasons and the feelings which I believe have prompted my mother to offer this gift to the Institution. It is often said that the best memorial of a man is the result of his life's work, and in many cases that statement is no doubt true. The whole personality of an artist or of a poet is reflected in his work, and is identified with him as a man for all time, so that he who reads or beholds can construct for himself, even though he has not known the man, and knows nothing of him except what he sees in his work, some sort of image of what he was; which, whether it be a good likeness or not, is at least satisfying in that it represents some definite individual. But I think that one whose labours have lain in pure science or in the construction of engineering works cannot hope for immortality of this sort. He adds, perhaps, a few stones to the vast and ever-increasing edifice of human knowledge, and at first no doubt those stones are identified with him and bear his individual marks. But as time goes on those marks are inevitably obliterated. The lines which divide his work from that of his contemporaries become less definite, and the stones that he laid become merged into the general whole. Other generations of workers and builders who knew him not pass up by the steps which he formed, their very footsteps, perhaps, assisting in the work of erasure; and if as they pass they remember his name at all it is probably rather as a label for that particular stage of their journey than as connoting the assemblage of qualities which constitute an individual man. I have no doubt that so long as dynamos are made, so long will the designers of such machinery, and the inventors of new forms of it, have first to master and then to use the fundamental principles which my father laid down. Among the workers in that field at the present time there are no doubt still many who knew my father personally or by repute, and to whom, say, a characteristic curve means something more than a mere piece of knowledge. And there are no doubt others still who

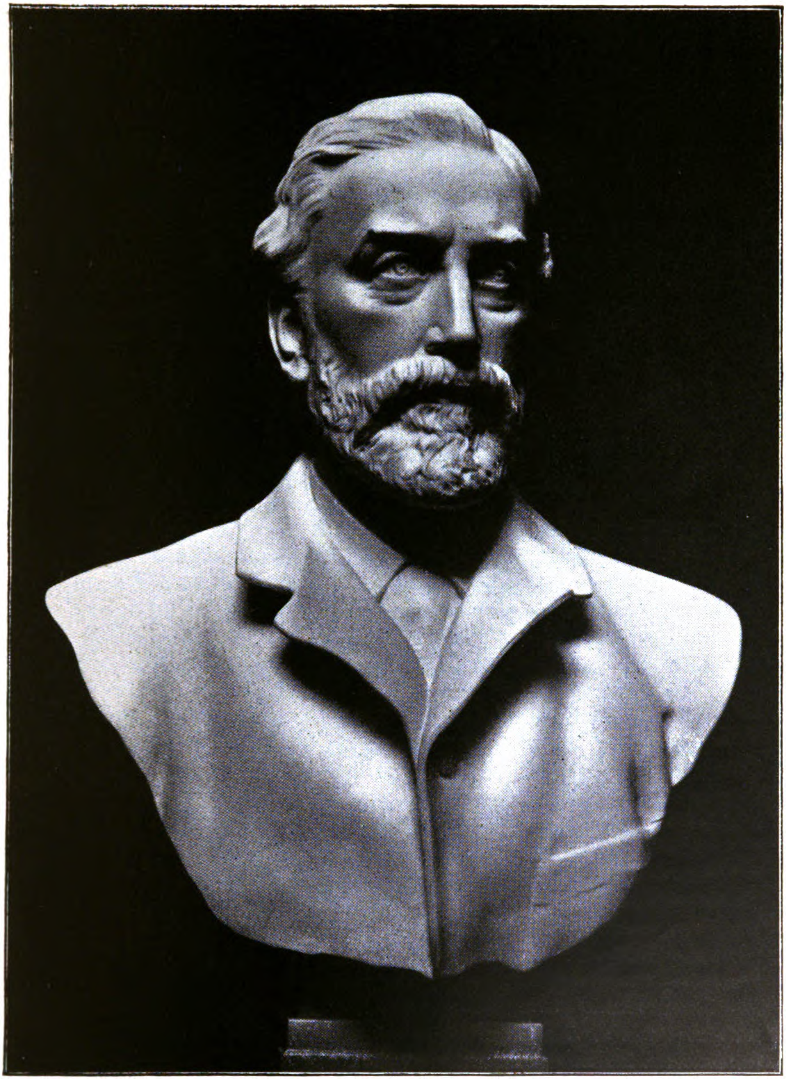
will occasionally turn to the original pages in which that knowledge was first embodied, and which bear something of his individual impress, just as the picture bears that of the artist. But in the course of a few years I think that that will no longer be so. The work will be there as valuable as ever, and men will use it; but to those who thus use it it will be merely a proposition—it will not be associated with any individual; and they will acquire it probably from some text-book written by a man who, in his turn, will have acquired it from yet another text-book. If the name of Hopkinson, the name of my father, is associated with the work at all it will be merely as a name.

It has seemed to my mother that when that time comes it will be a good thing if there is something which will help to clothe the name with some of the attributes which it bears for us who knew my father; it will be a good thing if there is something to remind those who use what will then be perhaps mere text-book formulæ that they represent the products of a human brain; and, further, that they were not mere intellectual achievements, but that, in addition to intellectual power, great qualities of character were important, nay, even essential, to their creation. It is in the hope that this gift may to some extent fulfil this purpose that my mother offers it for the acceptance of the Institution, and asks that it may be placed in the permanent home of the Institution. A man of tact and discernment who knew my father well has, then, by the exercise of unrivalled artistic power, expressed in marble his view of what my father was as a man. No sculptor who ever lived could indicate on a single block of marble all the many phases of character of his subject; and we shall not find there, for example—nor could we expect to find—the almost fierce energy of enthusiasm which many of us knew so well in John Hopkinson. But I believe that in years to come, and, indeed, for all time, men will read in those features the calm, impersonal judgment which he was wont to apply to the affairs of life—to its successes as well as to its difficulties—the force of will which enabled him to mould circumstances and persons, and the good heart and simple nature which won for him the esteem of all who knew him.

Professor Hopkinson then formally presented the bust.

The PRESIDENT (Mr. Mordey): Ladies and gentlemen, it is a great pleasure to me that it falls to my lot to express, on behalf of the Council and on behalf of the more than six thousand members of this Institution, our deep thanks to Mrs. Hopkinson for this gift. I do not fear that Hopkinson's name will ever be forgotten as long as electrical engineering is practised. The Romans had a law, I believe, that no man should have a statue erected in his honour until he had been dead a hundred years. I am quite sure that a hundred years from the time of the loss of John Hopkinson, he will still be considered worthy of a statue. I think that next to Faraday, whom we look upon as the scientific father of our industry, we electrical engineers owe more to Hopkinson than to any other man. It was Mrs. Hopkinson's intention that this bust should be presented when the Institution first occupied its new building.

When I told her about that building, she at once said she would like to know whether the Council would care to accept a replica of the Cambridge bust of John Hopkinson. I need not tell you what my reply was, nor how gratified the Council was when I reported to them her offer. Hopkinson was our President twice—in 1890 and again in 1896. A great many of us knew him, and we appreciated not only his great scientific and engineering work, but his character as a man. His scientific work covered many fields beyond that embraced by the objects of this Institution, but I may be allowed to mention a few of the many things that we owe to him—things that may be looked upon as landmarks in connection with the development of electrical engineering. It was in 1883, before the Institution of Civil Engineers, that Hopkinson first developed by theoretical treatment the subject of the parallel working of alternate-current machines; it was in 1884 that he followed that up by a practical demonstration at the South Foreland Lighthouse. On that occasion it is interesting to remember that he was assisted by another Past President of ours, Professor Grylls Adams, who, I am sorry to say, is not here to-night. This was a subject that had made no advance since our Honorary Member, Dr. Henry Wilde, had written and worked on it in 1869—work that had been overlooked and forgotten. Then in the next year (1885) before the Royal Society, Hopkinson read a very important paper on the magnetisation of iron, a paper that I think I may say has in that subject been the standard ever since. The methods that were applied then, and the knowledge that was given by him in that paper, have been taken as models, I think, by everybody who has since worked on that subject. Then in the next year, 1886, he applied the results of this physical research to practical purposes in his famous paper on dynamo electric machinery, which was read before the Royal Society in conjunction with Dr. Edward Hopkinson, his brother, whom we are glad to welcome here to-night. I think I may say the universal opinion of electrical engineers is that that paper raised the knowledge of the dynamo from chaos into engineering and scientific order. A year or two afterwards he wrote another very remarkable paper on the properties of iron at high temperatures, a purely physical investigation, but one of very great interest—one that I think showed perhaps as much as any of his papers his insight as an investigator. One of the most interesting things in that paper to me, and probably to many of you, was the discovery of the enormous increase of magnetic permeability in iron at a temperature a few degrees below that at which it becomes non-magnetic. You will remember he discovered that the permeability at that point at a certain low magnetic force, and only then, becomes about ten times as great as at ordinary temperatures with the same magnetising force, a discovery that has never been made practical use of, and perhaps never may be, but it has always seemed to me to be one of very great physical interest, and one that showed Hopkinson's great power as an investigator. I need not refer to his work on the improvement of the optical arrangements of light-



JOHN HOPKINSON, DSc., F.R.S.

PRESIDENT OF THE

Institution of Electrical Engineers

1890 and 1896

From photograph of marble bust by HAMO THORNYCROFT, R.A., *presented to the Institution by* MRS. JOHN HOPKINSON, *November 11th,* 1909.

houses—important work that he carried out as consulting engineer to the great makers of lighthouses, Chances, before he became prominently connected with electrical engineering—that is outside of our scope. Neither need I refer to his work as an inventor—we owe the 3-wire system to him—nor to his fruitful work as an engineer, nor to his work as a teacher—I am glad to say that we have at least one of his pupils here with us to-night on the Council. But whatever I omit I must not fail to remind you of Hopkinson's patriotism. It was in January, 1896, when Hopkinson came here to take for the second time the Presidency of this Institution that he preceded the reading of his inaugural address by a statement which has borne very good fruit. I was here, I am glad to say, and many of you were here also. Let me recall that night. The country was in a state of agitation and anger. A few of our countrymen had done an unwise thing. A certain eminent personage had sent a telegram which had increased the difficulties of an already very difficult position. Hopkinson's answer to the telegram was an invitation to this Institution to form a corps of electrical engineers. He asked for help to render available for purposes of national defence the technical skill of electrical engineers. You will remember what the result of that was. The corps of Electrical Engineer Volunteers was formed, and Colonel Crompton, the President who that night gave up the chair to Hopkinson, was called upon shortly afterwards to command that body in the field of actual war in South Africa. I think I may say that the result of that action of Hopkinson's went even further than the formation of that corps. I think to that we may trace the present very close connection and association between the War Office and this Institution, and one or two other engineering institutions. This memorial of a great electrical engineer will have an enhanced value to posterity —as it has to us—because it is the work of so distinguished an artist as Hamo Thornycroft. It will stand in good company in our new home—amongst its companions will be the bust of Volta, presented to us by the Associazione Elettrotecnica Italiana, that of Benjamin Franklin, the gift of the American Institute of Electrical Engineers, and that of Sir Francis Ronalds, to whose generosity and learning we owe the Ronalds Library of electrical books. The eloquent and most instructive address of Professor Hopkinson—who in so many ways reminds us of his father—has added greatly to the interest of this presentation. I will only say one other thing, and that is, that the honour of occupying this presidential chair, which I occupy to-night for the last time, will always be the greater from the fact that it has been occupied twice by Hopkinson. I ask you to pass a hearty vote of thanks to Mrs. Hopkinson for her gift.

The vote of thanks was carried by acclamation.

The PRESIDENT (Mr. Mordey): Before I ask my successor to take my place, there is one short explanation I might give. Members may wonder when we are going to occupy our new building. It was hoped when the building was bought that we might be able to use it for part of this

session, but it has been arranged that we make no use of it till June next year. The new theatre is being rapidly proceeded with, as well as the alterations to the hall that give access to that theatre. We could easily have moved our library and offices into the building, but for various sufficiently good reasons the Council thought it better not to attempt to go into the building at all until it was completely ready for occupation as the Institution of Electrical Engineers. We shall therefore move in next June, and a year hence probably the first actual general meeting of the Institution will be held in the new theatre. It will not be possible to occupy it before June, and therefore it will not be available for this session.

I now call upon Dr. Kapp to take my place and to read his Inaugural Address. Dr. Kapp needs no introduction from me, rather the contrary. I must not occupy time that I know will be more profitably taken up in listening to his address, but I would like, as I have spoken of Hopkinson, to mention one thing that I think is sufficient, if he had done nothing else, to place Kapp in the high position he has always occupied in our regard, and that is that in 1886, a very short time after John and Edward Hopkinson read their famous paper on the dynamo, Kapp read a paper here "On the Pre-determination of the Characteristic," in which he worked out quite independently important practical results which formed one part at least of the Hopkinson paper. That was, I think, work of a very high order, and we know well that, before then and since, Dr. Kapp has always been prominent in connection with everything to do with electrical engineering. I have very great pleasure in vacating this chair in his favour.

The chair was then vacated by Mr. Mordey, and taken by the new President, Dr. Gisbert Kapp.

Mr. Alexander Siemens: As the oldest Past President attending the meeting, I have very great pleasure in moving: "That the best thanks of the members of the Institution of Electrical Engineers be given to Mr. W. M. Mordey for the very able manner in which he has filled the office of President during the past twelve months." The members of the Institution have had the opportunity of seeing Mr. Mordey in the chair at the meetings of the Institution, and I am sure they must have come to the conclusion that he has conducted those meetings as well as any preceding President, to put it very low indeed. But we members of the Council have had an opportunity of seeing him at work at the Council Meetings and Committee Meetings; and all I can say in that connection is that if the new building turns out to be to the satisfaction of the members, it will be in a great part due to the personal exertions of Mr. Mordey. I have therefore great pleasure in moving the resolution.

Mr. J. Swinburne: I have great pleasure in seconding the motion that has been moved by Mr. Siemens, because I think we all realise that Mr. Mordey has had a very arduous year of office, and that he has done splendid work for the Institution in connection with the new

building. But we must also remember that Mr. Mordey has not come amongst us during the last year. Like most Presidents of this Institution, Mr. Mordey has a past, and we must remember what the Institution owes to Mr. Mordey for all the papers he has brought forward. Mr. Mordey has always been in the forefront through the papers he has written on every subject as it has arisen in connection with our industry, and his papers have been all the more valuable because generally we have not agreed with them—not that that is in the least evidence that he is ever wrong. I will not take up your time any more, because I am sure we all want to hear the address of our esteemed President.

The PRESIDENT (Dr. Gisbert Kapp): It is a great pleasure to me that my first official action in this chair is to ask you to pass the vote of thanks to our Past President.

The resolution was carried by acclamation.

Mr. W. M. MORDEY: Gentlemen, I will not occupy more of your time. Anything that I may have been able to do on the Council or at these meetings has been due to the cordial, loyal, and constant help I have had from my fellows on the Council. I have often wondered why I was made President, because I have done very little, and I have made mistakes. I think it is because my fellow engineers realise that at least I have tried. I thank you very much.

The President then delivered his Inaugural Address.

INAUGURAL ADDRESS

By Dr. GISBERT KAPP, President.

GENTLEMEN,—First of all allow me to thank you for the great honour conferred upon me in electing me to this chair, and to say that I am fully conscious of the responsibility which lies on the President of an Institution which, in point of membership, is the second largest in the kingdom. Although, strictly speaking, electrical engineering is only one branch of the great engineering profession so well represented by the Institution of Civil Engineers, whose kind hospitality we have enjoyed for many years, it is a branch which entwines with all others. Electricity has become an indispensable helpmate to all engineers, and its general usefulness has caused electrical engineering to make enormous strides within the time of the present generation, and the number of those who enter our profession has largely increased. From the List of Members I find that in midsummer of this year we had 7 Honorary Members, 1,142 Members, 2,387 Associate Members, 1,042 Associates, 1,432 Students, 107 Foreign Members—in all 6,117 Members of our Institution. It is satisfactory to find such a large number of Students, as this shows that the rising generation appreciates the importance of electrical engineering, and justifies the hope that with so large an influx of fresh and vigorous intellect our Institution will continue to prosper.

It has usually been the custom for the President to deal in his Address with his own special branch of professional work, and since for a number of years I have, both in Germany and over here, taken an active part in the teaching of electrical engineering, I was tempted to make this the subject of my address. The question has, however, so often been discussed in recent times, that I fear it would be wearying you to go over old ground again. Moreover, technical education, although a most important subject, has a direct interest only for a small number of the members. Some of us have to train men so that they may make or use electrical apparatus, but by far the greater number of us are either makers or users of such apparatus, and for this reason I propose to follow the example set ten years ago by a former President, who, in his Address from this chair, passed in review the then state of electrical engineering. The industry has grown so enormously in the last ten years that it would be quite impossible, in the limited time available for a Presidential Address, to give anything like a complete account of it, and I must therefore content myself with

drawing attention to a few only of the novel features in design of electrical apparatus, and to a few among the many applications of electricity to industrial processes. Even with this restriction I can only deal with the subject in a general way, and for more detailed information I must refer the members to other publications which are mentioned in footnotes.

Before entering into technical matters, I will take a comprehensive view of the industry as indicated by the capital invested. In this I am also following the lead of my predecessor—Dr. S. P. Thompson—who, at the end of his Address, gave from Garcke's Manual a list of undertakings with the capital represented by each. I have added (also from the same useful source of information) the figures for the middle of this year, that is ten years later than the table given in Dr. S. P. Thompson's Address.

Undertaking.	1899.	1909.
	£	£
Telegraphs*	34,284,957	36,283,038
Telephones	7,729,626	22,132,641
Electricity supply companies ...	9,265,793	45,743,744
Electricity supply municipalities ...	8,531,167	51,796,604
Electric traction	20,808,959	185,192,296
Electric manufacturing	16,799,152	42,486,269
Electrochemistry and miscellaneous	8,558,065	12,253,622
Total	105,977,719	395,888,214

* Exclusive of Government Telegraphs.

We may take our membership as a rough indication of the number of persons engaged in the electrical industries. In 1899 our membership was 3,254, now it is 6,117—nearly double; but the capital employed in these industries is nearly quadrupled, so that the efficiency of labour, both mental and manual, has increased by about 70 per cent. Or, to put it in another way, each man or group of men can now produce, control, or utilise, 70 per cent. more wealth than the same man or group of men could produce, control, or utilise, ten years ago. This shows that we have made considerable technical progress.

I have just made the distinction between design and application of electrical apparatus. This distinction is not always easy to maintain, because new uses of electricity demand new designs, and the two are so interdependent that a hard and fast demarcation line can hardly be drawn, but for my present purpose a rough division may usefully be made into two great groups: first, the design and manufacture of

electrical machinery and apparatus; and secondly, the application of electricity to various industrial purposes. I can only indicate some of the more important developments and general tendencies without attempting an exhaustive treatment of the subject.

GENERATORS.

The modern tendency is to instal very large units. This is partly due to the large demand made on the power house and the desire to restrict the number of units, and partly to the fact that the advantages of the steam turbine over the reciprocating engine become more pronounced with the increased size of the unit. The General Electric Company of New York have built several turbo-alternators of 14,000 k.w. at 9,000-volt pressure, and the British Westinghouse Company inform me that it would be quite feasible to build sets of 15,000 k.w. up to 13,000 volts, or, if necessary, 15,000 volts pressure. In water-driven alternators, also, the tendency is towards large units. Thus the power house of the Norwegian Nitrogen Company at Svälgfos, near Notodden,* has been fitted up with four turbine-driven 3-phasers, each for 10,500 kilovolt-ampere, and developing 7,000 k.w. at a power factor of 0·67, the speed being 250 revs. per minute, and the terminal pressure 10,000 volts at 50 frequency. The stator is 3,500 mm. in internal diameter, and 1,150 mm. long. The total losses at full load amount to 320 k.w., corresponding to a generation of heat of 270,000 calories per hour for each machine. It is obvious that in these circumstances special ventilating arrangements become necessary. Air ducts are carried under the floor to each machine, but no provision is made to carry the heated air away; it simply discharges into the engine-room. Dr. M. Kloss,† in a paper read before our Institution about a year ago, has pointed out that the scientific way of ventilating turbo-dynamos is to take the air from the outside and discharge it to the outside of the engine-room. The first part of his recommendation is already being followed in modern stations, though the hot air is generally discharged into the room. There is, however, no difficulty in arranging for a discharge through ducts under the floor, and this would certainly conduce to the comfort of the engine-room staff. No separate ventilator need be provided; it is quite easy to mount a fan on each end of the rotor, and so to case in the whole machine that the air is forced along prescribed paths. In the machines made by some large Continental firms this path is as follows: From the ducts underground into annular chambers surrounding the rotor shaft, then through fan-wheels of the "Sirocco" type into annular chambers on either side of the stator ends, through longitudinal holes in the stator iron, and radially outwards through the air discs of the stator. The hot air is thus discharged into a cylindrical space surrounding the stator, and may be finally let out either at the top into the room or at the bottom into a

* *Zeitschrift des Vereines Deutscher Ingenieure*, vol. 53, p. 684, 1909.
† *Journal of the Institution of Electrical Engineers*, vol. 43, p. 160, 1909.

discharge duct. It is important that only clean air be used, and for this reason air filters are built into the inlet ducts. These are formed of pockets of porous cloth extended over wooden frames, and so placed that the dust which settles on the cloth may be removed by beating or with a vacuum cleaner. Washing or chemical cleaning is only required after some years of use.*

In most modern electricity works the circulating and air pumps are driven by electric motors, but this method has been replaced at the

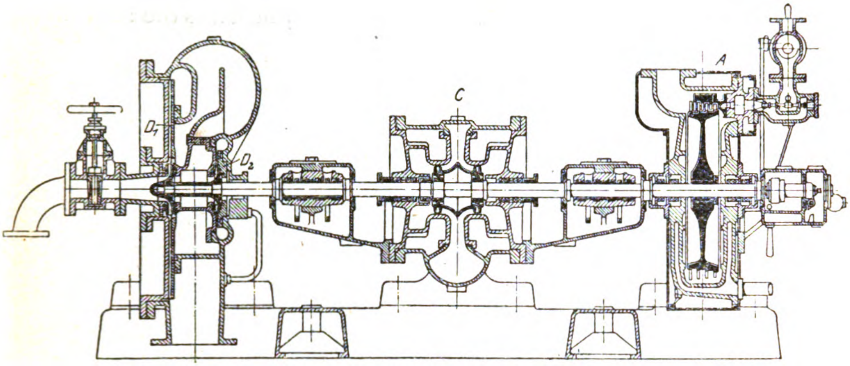


FIG. 1.

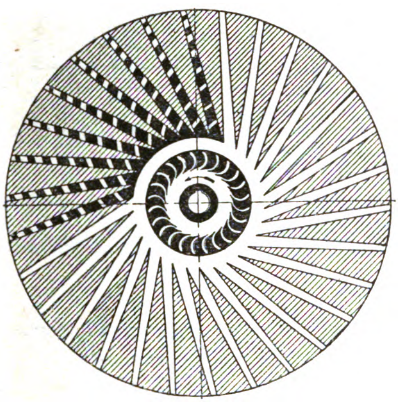


FIG. 2.

works of the Allgemeine Elektricitäts Gesellschaft by a set of turbo-driven centrifugal pumps. Figs. 1 to 4 show the arrangement for a 6,000-k.w. turbo-alternator.† *A* is a small steam turbine running at 2,000 revs. per minute, which drives the circulating pump *C*, the air pump D_1, and a pump D_2, which forces the water into the inlet chamber of the feed pump, the latter being also of the centrifugal type. No piston pumps

* *Zeitschrift des Vereines Deutscher Ingenieure*, vol. 53, p. 701, 1909.
† Ibid., pp. 703–4, 1909.

at all are used, and the feed may be regulated without paying attention to the feed pump. The space saved by this modern way of dealing with the exhaust of turbos is shown in Figs. 3 and 4, both drawn to the same scale for two 6,000-k.w. turbo-condensers. Fig. 2 shows the principle on which the air pump works. Water is admitted through the inlet valve on the left of D_1 (Fig. 1), and is discharged by the centrifugal pump wheel into a diffuser surrounding it, as shown in Fig. 2. The annular space between fan and diffuser is in communication with the condenser, and the water flying across this space takes the air with

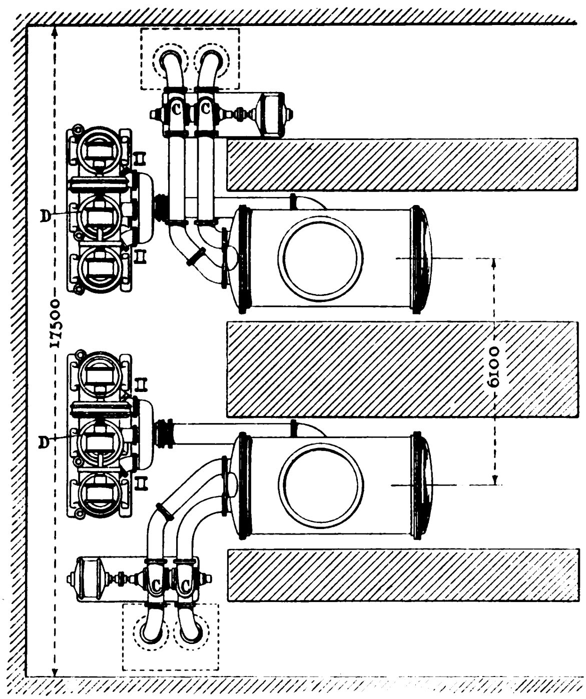


FIG. 3.

it and discharges it at atmospheric pressure at the outer circumference of the diffuser. The individual particles of water act as so many tiny pistons compressing and forcing the air forward ; this is indicated in the figure by the black shadings in some of the diffuser channels. The water, which has been used for expelling the air, joins the water coming directly from the condenser, and is dealt with by the pump D_2, as already mentioned. Mr. Lasche, the writer of the article from which I take this information, says that the feed water obtained by this method is absolutely free from air, and that only 5 per cent. of make-up

for the feed is required. Since no piston engines of any kind are used there is no need for oil filters.

An important development in turbo sets was initiated about ten years ago by Professor Rateau with his exhaust steam turbine, and as far back as 1902 the Hon. C. Parsons made such a machine, but it is only recently that the commercial importance of these turbines has been fully recognised. In a paper read by Mr. R. F. Halliwell before the Rugby Engineering Society, particulars of several installations are given, from which it appears that the cost of adding exhaust steam turbo sets to an existing installation of large size may be taken at from £6 to £10 per kilowatt exclusive of thermal storage. I take from a German

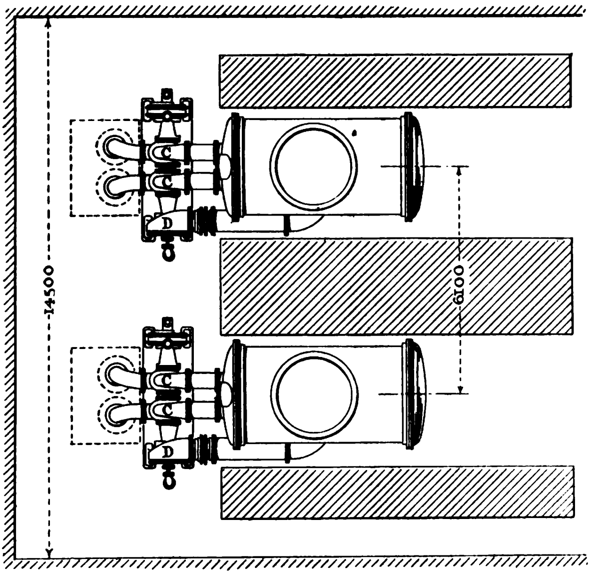


FIG. 4.

mining paper* the following particulars of an exhaust steam turbo plant that has recently been erected in the Osterfeld Mine in Westphalia. From the existing winding engines, compressors, fans, and other steam engines a maximum of about 50 tons of steam per hour was available. The exhaust is taken into four Rateau thermal storage vessels at about atmospheric pressure and from there to two 1,600-k.w. Rateau-Brown-Boveri turbo sets. The capital outlay was £58,000, or £18 per kilowatt. This high cost is due to the circumstance that the intermittent character of the supply of exhaust steam necessitated the installation of a rather large thermal storage plant. With a yearly output of 17 million units and allowing 10 per cent. on the capital cost for fixed

* *Glückauf*, vol. 44, p. 1721, 1908.

charges, and also making allowance for a certain amount of live steam required to tide over gaps in the delivery of the winding engines, the cost per unit works out at 0·13d., whereas with an independent installation the cost of the unit, as shown by other installations in the district, would have been 0·42d. The use of exhaust steam turbines thus results in an annual saving of about £20,000. That is 34·5 per cent. on the capital outlay.

A point which requires careful attention in the design of generators is the permissible drop. For safety a large drop is desirable, whilst for regulation both the inductance and the demagnetising force of the armature should be kept as small as commercially possible. Thus the best design is as usual a compromise, but by an ingenious method devised by Mr. Miles Walker and adopted by the British Westinghouse Company this compromise has been made less difficult, especially in the design of turbo-driven alternators. The exciting coils are housed as usual in longitudinal slots in the rotor, but instead of arranging these coils symmetrically to the polar axis, Mr. Walker places the centre of the coils nearer to the leading edge of the pole, so that the teeth in that part of the rotor are more strongly magnetised than the teeth in the polar axis, whilst the magnetisation is weaker still in the teeth in the lagging polar edge. If the machine works at a power factor not much less than unity, the armature currents weaken the induction over the leading and strengthen it over the lagging polar edges. Since the latter are not highly magnetised to begin with, this strengthening action can take place fully, whilst the weakening action on the leading edge has much less effect on account of the initial saturation. Thus on the whole there may be no change or even a slight rise of total flux with an increasing load, so that the armature back magnetisation is compensated. This compensation fails, however, if owing to a short there is a great increase in armature current, for then this current lags so much that the pole as a whole is demagnetised, and the machine is in no worse condition than a machine of the usual type designed for a small short-circuit current.

The desire to reduce the cost and complication of a switchgear and to make paralleling easy has led to the use of non-synchronous machines as generators. It is well known that if the rotor of an induction motor be driven by power at a little over synchronous speed, the machine will act as generator. Such a machine, especially if turbo driven, has important advantages over the ordinary generator having the usual field system with continuous-current excitation. The machine can, of course, only work if excited with alternating current from the busbars, so that such machines are generally installed when an enlargement of existing plant becomes necessary. The rotor may be a squirrel-cage of very simple construction and requiring hardly any insulation, no matter how high the pressure produced by the stator may be. The mechanical construction is easier than that of the revolving field of an ordinary turbo-alternator, and since the air space can be made small, the power factor is high. A 5,000-k.w. non-synchronous generator has last year been added to the plant of the Inter-borough Rapid Transit Company,

New York.* This was supplied by the General Electric Company of America. In Europe the Oerlikon works have supplied such machines. Professor Niethammer † calculates the power factor of a 10,000-k.w. non-synchronous generator running at 750 revs. per minute and producing 2,200 volts at 25 frequency to be 0·982, and the efficiency 0·985. He also advocates the use of such generators in connection with converters for railway sub-stations, in which case no other source of alternating current would be required, the converter itself producing the excitation of the generator. He estimates the overall efficiency of a 3,000-k.w. set at 0·96. I do not know whether his suggestions have yet been adopted in practice, but I mention them as a possible and interesting development.

There is some difficulty in the design of turbo-alternators for very low periodicity, since the speed becomes insufficient for the satisfactory working of the turbine. To meet such cases Mr. E. Ziehl has devised a type of alternator which he calls a "double-field generator" (Doppelfeld generator).‡ The principle may be explained as follows: Imagine a non-synchronous motor having precisely the same 3-phase winding in stator and rotor, and let the circuits be connected either in series or parallel in such way that a 3-phase current sent through the machine will produce fields which in stator and rotor revolve in opposite sense. If now the rotor be driven by power in a sense opposite to that of its own field and with a speed corresponding to twice the frequency, the field produced by the rotor currents will in magnitude and direction of motion be identical with that produced by the stator currents. Thus each of the two windings contributes one-half of the field common to both. At the same time the demagnetising action of each winding is eliminated by that of the other. The machine cannot work alone, but must be excited in the same way as a non-synchronous generator from some synchronous generator; it cannot give a wattless current, and in an installation where the power factor is less than unity the synchronous machine must supply the wattless currents. As advantages Mr. E. Ziehl claims the following: Since the E.M.F. is generated in both windings only half the flux as compared to a synchronous generator is required; hence less hysteresis loss, smaller radial depth of stampings, and less copper weight, which is due partly to the small air-space and partly to the shorter pole-pitch. All these tend to reduce the cost of manufacture. Since the machine can only give a watt current, a short circuit on the mains cannot damage it. The paralleling is easy; the speed need only be approximately right, and if coupled up in a wrong phase position no damage is done, since the inductance is then very great. It is only when running at exactly synchronous speed, and in correct phase position, that the mutual compensation between the two windings takes

* R. F. Halliwell, paper read December 17, 1908, before the Rugby Engineering Society.

† *Zeitschrift des Vereines Deutscher Ingenieure*, vol. 53, p. 1009, 1909.

‡ *Elektrotechnische Zeitschrift*, vol. 26, p. 617, 1905, and vol. 30, p. 473, 1909.

place, and if the machine be switched on when out of phase it pulls itself quickly into phase without demanding from the busbars a large synchronising current. When used in connection with converter sub-stations no separate alternating excitation is required, the converter itself acting as exciter. Mr. Ziehl has published tests made on small machines,* but I do not know whether since this first publication the system has been tried practically on a large scale.

TRANSFORMERS.

Thanks to the researches of Sir Robert Hadfield which have resulted in the production of the excellent material known as alloyed iron, † the science of transformer making has developed in a remarkable degree. In transformers also there is to be noticed a general tendency towards large units, which is not surprising if one considers that for the calcium carbide industry alone about half a million horse-power in generating plant has been installed throughout Europe, and that most of the power has to flow through transformers to the carbide furnaces.

The General Electric Company of America have built for the Great Western Power Company on the Feather River several 10,000-k.w. 3-phase transformers working at 60 frequency, and giving a pressure of 100,000 volts.‡ The makers claim an efficiency of nearly 99 per cent. at full load. The transformer is placed in an oil tank cooled by water, 18 ft. in height, and occupying a floor space of 18 ft. by 9½ ft. The weight of this transformer is given as 54 tons, and the quantity of oil required as 7,500 gallons. This would make a total weight of about 85 tons.

The largest European transformers of which I could find a record are some made by the Siemens-Schuckert Werke. They are of 3-phase 6,750-kilovolt-ampere capacity oil cooled, for 66,000 volts on the high-pressure side. The cooling arrangement is unusual, but probably very efficient. It is shown in Fig. 5. Usually the case is made much higher than the transformer, and the upper part is used for housing the water pipes. The oil on being heated by contact with the transformer, rises and gives up heat to the pipes and then descends again to take up more heat from the active material. In the arrangement here shown the case is just high enough for the transformer, and no attempt is made to cool the oil in the case, but by means of an oil pump a definite and forcible circulation within the case is induced, whilst at the same time the oil being passed through a worm outside can be effectively cooled. This arrangement is especially useful in cases where the cooling water is dirty, and there would in consequence be the danger of a water worm of the usual type becoming choked up. The use of oil as a filling medium has made it possible to build transformers for very high pressure. In one American power-transmission plant now under construction the step-up transformers are intended to raise the pressure to 110,000 volts, but even higher pressures

* *Elektrotechnische Zeitschrift*, vol. 30, p. 473, 1909.
† Known under the trade name "Stalloy."
‡ *General Electric Review*, vol. xi. No. 4, October, 1908.

can be obtained. Transformers giving extremely high pressure on the secondary are used for testing insulators and insulating material. A transformer of this kind has recently been made by Messrs. Brown-Boveri. It is a 50-kilovolt-ampere transformer wound for a primary pressure of 1,000 volts and giving on the secondary 250,000 volts, but even this has been exceeded when the transformer was used in testing the dielectric strength of insulators. From a curve referring to such tests which the makers have sent me I find that the highest pressure recorded was 310,000 volts.

The reduction in weight of transformers due to the use of alloyed iron, large units, and vigorous cooling is very remarkable. As an example of good modern practice I take a Brown-Boveri transformer

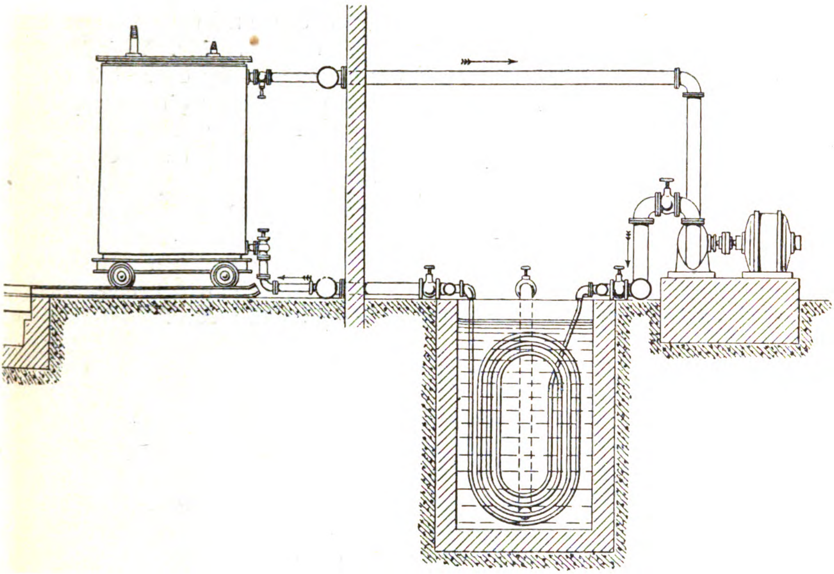


Fig. 5.

for 4,600 k.w. at 27,000 volts, 50-frequency, 3-phase, oil-cooled, with water coils in the case. The active material, by which term I mean the iron carcase and copper coils, but exclusive of case or fittings, weighs only 3·1 kg. per kilowatt, and the efficiency is 98·6 per cent. at full non-inductive load. In an Oerlikon 3,500-k.w. transformer the active iron only weighs 7 tons, being at the rate of 2 kg. per kilowatt output. Its efficiency is also nearly 99 per cent. This transformer is the more remarkable as no oil is used. It is a so-called dry transformer with forced draught, yet the voltage on the high-pressure terminals is 27,000 volts. Such an arrangement is safe enough in the pure air of the high Alps, but it would evidently be risky to adopt it in a town like London or Birmingham for any but a moderate pressure. Generally the modern

tendency is to rely on oil for insulation, and, for units above a certain size, on water as the cooling medium. The largest self-cooling oil transformers of which I know are some 1,200-k.w. 3-phase 40-frequency 5,000-volt transformers made by the British Westinghouse Company, but for larger unit artificial cooling becomes necessary. In some 1,850-k.w. transformers made by the same firm the cooling is effected by an air-blast directed against the outside of the case. The Siemens-Schuckert Werke have also employed the principle of cooling the outside surface of the case, only in this case the cooling medium is water which is sprayed against the case.

The aim of the designer of transformers for power or light supply is to reduce the inductive and ohmic drop as much as possible. If, however, the transformer is intended for furnace work it is better to allow a rather large inductive drop so as to reduce the rush of current in the event of a short circuit in the furnace. Mr. Yazidjian * has pointed out that the power factor of the primary current is not much lessened thereby, whilst the element of safety thus introduced is worth having. A large inductive drop means wide spaces between primary and secondary coils, thus facilitating insulation and cooling, but it also involves the necessity for good mechanical support. The mechanical forces acting on the individual coils are due to leakage fields, and where these are considerable the mechanical stresses on the coils are also considerable. This is probably the reason why some makers prefer the core type with concentric cylindrical coils, the cylinder being the best shape for resisting radial forces.

Motors.

The establishment of power-distributing systems on a large scale has strongly stimulated the manufacture of alternating-current motors, and nowadays this type of machine is built by nearly all makers of dynamos. The manufacture has become perfectly standardised, and no startling improvement can be expected in the ordinary induction motor. Inventors are, however, busy in devising means for reducing the speed of such motors, and in this connection I must draw your attention to the principle of cascade working which has recently been developed by Mr. Hunt of the Sandycroft Foundry. The ordinary cascade as used on electric locomotives requires two motors, the rotor of one sending current into the stator of the other. Mr. Hunt has, by an ingenious method of grouping the coils, succeeded in adapting the cascade principle to one motor only. He is thus able to run an 8-pole motor at the speed of a 12-pole motor whilst getting a better power factor than is possible with the orthodox way of using two motors in tandem. As he has offered a paper on this subject to this Institution, I will not anticipate his communication by a further description. In 3-phase motors for railway work speed regulation is obtained either by some kind of cascade arrangement or by changing the

* *Elektrotechnische Zeitschrift*, vol. 30, p. 57, 1909.

number of poles. In either case the rotor has slip-rings, and if the pole-changing system is adopted there will be more than one set of slip-rings, since the number of poles in stator and rotor must be the same. In the confined space available for a traction motor it is not easy to find room for slip-rings, whilst the maintenance of these and their brushes is also an item that one would gladly avoid. This is now possible, thanks to an ingenious design worked out by Mr. Aichele, the chief designer of Messrs. Brown-Boveri. The motor has been applied in their latest Simplon locomotives, and a description of it has recently been published by Messrs. E. Thomann and K. Schnetzler.* The rotor is simply a squirrel-cage, and has no slip-rings and no outside electrical connections whatever. The bars are ventilated copper tubes, and the end connections are designed to stand a temperature of 200° to 250° C., when an exceptionally large starting current is developed. At the same time, the resistance of the rotor as a whole is raised some 40 per cent. owing to the temperature coefficient of the end connections. The latter cool rapidly as soon as speed is attained, and the rotor then works with normal slip. The stator has two distinct windings, one for 16 and the other for 12 poles, and each winding can by means of a pole-changer be so grouped as to produce half its normal number of poles. There are thus four normal speeds possible, corresponding respectively to 16, 12, 8, and 6 poles, or to a train speed of from 26 to 70 km. per hour. At starting the pressure is reduced by an auto-transformer and thrown at first on to the 16-pole and then on to both the 12- and the 16-pole windings in parallel. Then the 16-pole winding and the auto-transformer are switched out and the train attains the speed of 35 km. per hour, which corresponds to the 12-pole winding acting alone at the full line pressure of 3,000 volts. To increase the speed further the 8-pole winding is added in parallel, then the 12-pole winding is switched out, then again switched in as a 6-pole winding, and finally the 8-pole winding is switched out, leaving only the 6-pole winding at work when the maximum speed is reached. The frequency is 16 per second. Each winding is connected with the pole-changer by 6 leads—that is to say, there are 12 leads in all required for each motor. No starting resistances are required. The ends of the stator windings are protected, but the inside of the rotor is freely accessible to the air. The power of the motor at the one-hour rate is given by Mr. Schnetzler as follows:—

Poles	6	8	12	16
Horse-power	850	750	650	550
Train speed—kilometres per hour...	70	52	35	26

A remarkable improvement in single-phase motors has been devised by Mr. Deri, and practically developed by Messrs. Brown-Boveri. Mr. Deri's motor may best be explained by reference to the original so-called "repulsion-motor" invented very early in the

* *Zeitschrift des Vereines Deutscher Ingenieure*, vol. 53, p. 607, 1909.

history of alternating-current engineering by Elihu Thomson. In this motor the rotor is of the same type as the armature of a continuous-current motor, but the brushes are short-circuited on each other, and are mechanically so arranged that the brush axis may be set at various angles to the axis of the stator field. If set at 90° (electrical) no current passes through the rotor, and if set co-axially, the rotor takes a maximum current, being in fact the short-circuited secondary of a transformer. In both these extreme positions no torque is exerted, but in an intermediate position a torque is exerted, and if the rotor is allowed to run, the current is reduced and the power factor increased. Mr. Deri employs two sets of brushes; one being fixed in the polar axis of the stator, and the other so adjustable as to include different angles with the fixed brushes. In a 2-pole motor there are thus four brushes required. The movable brushes are not shorted on each other, but each is shorted on its corresponding fixed brush. If the fixed and movable brush are in line and bearing on the same part of the commutator, no current passes through the armature. If their angular distance is 180° the armature winding acts as the shorted secondary of a transformer. In neither case is a torque exerted. If, however, the angular distance between fixed and movable brush is intermediate between 0° and 180° a torque is exerted, and if the armature is allowed to run the current decreases and the power factor increases. The effect of shifting the brushes is analogous to changing the impressed voltage on an ordinary continuous-current series motor, and thus by adjusting the brushes the torque and speed may be regulated. This property renders the Deri motor valuable in all cases where delicate speed regulation is essential. It is largely used for working passenger lifts and other hoisting machinery, and also for driving ring-spinning frames, the speed regulation in the latter case being automatic. The result of automatic speed regulation is an increased output from the ring-spinning frames. Another application is for electric railway working to which I shall refer later. An important point in these motors is their perfect commutation. I have a 6-H.P. 50-frequency Deri motor in my laboratory at the Birmingham University, and this works absolutely without sparking at any load and speed within its range.

The well-known Winter-Eichberg motor as first developed for railway work had a series characteristic; recently Mr. F. Eichberg has altered the winding so as to give the motor a shunt characteristic, so that it runs at constant speed whatever the load within its range. The motor is started as a series machine, and when up to speed, or nearly so, it is switched over by its controller to the shunt condition. With a motor of this type in my laboratory I have found the inventor's claim that the power factor is very nearly unity at all loads quite borne out in practical work.

I must now leave the subject of design and direct your attention to that of application of electricity to some important industrial developments. The first to claim consideration is

The Electric Transmission of Power.

There has been a considerable development in this branch of applied electricity in late years, but the development has been on different lines in different countries corresponding to their various topographical, industrial, and commercial conditions. With us it is not so much a question of carrying power a long way, as of distributing large amounts of power at numerous points within a restricted and densely populated area. For so-called water-power countries the problem is different. Although the district where the power is wanted may also be densely populated, the amount of power required per square mile is less than with us, whilst the distance between the source of the power and the points of its delivery is very much greater. Hence the necessity of using very high pressures in the transmission lines. In England a pressure of 20,000 volts may be considered as an upper limit for most cases, but on the Continent and in America higher voltages are very often necessary. As instances may be taken the transmission of 3,900-k.w. at Gaucin-Sevilla * over a distance of 125 km. at a pressure of 52,000 volts and that of the Hydroelectric Power Commission of Canada † over 500 k.m. at 110,000 volts. The voltage is limited not so much by the dielectric strength of the insulators as by dispersions of electricity through the air and the consequent loss of power. In this connection some admirable experimental work has recently been done by Mr. Ralph D. Mershon ‡ to determine the maximum voltage which may be used under given conditions on an overhead 3-phase line. He gives the following formula as a near approximation to the experimental results. 'The limit of pressure beyond which dispersion causes sensible loss of power is in virtual kilovolts—

$$KV = \left(\frac{1}{1 + K_4 p'}\right) K_1 \left(1 + \frac{K_2}{K_3 + r}\right) r \log\left(\frac{s}{r}\right).$$

where K_1, K_2, K_3, K_4 are constants, p' is a quantity which Mr. Mershon calls the "vapour product," r is the radius of the wire, and s the distance between the two wires between which the pressure KV exists. It will be noticed that the temperature does not directly enter into Mershon's formula, though it is implicitly contained in the value p', whereas Ryan's old formula contained the temperature itself. By taking Mr. Mershon's curves and assuming proportionality between the barometric pressure and critical voltage as in Ryan's formula§—

$$\left(E_{max.} = \frac{17{\cdot}94\, b}{459 + t} \times 2{,}055 \log_{10} \frac{s}{r} \times D' \times (r + d) \times 10^{10}\right).$$

* *Zeitschrift des Vereines Deutscher Ingenieure*, vol. 53, p. 924, 1909.

† *Elektrotechnische Zeitschrift*, vol. 30, p. 328, 1909, and *Zeitschrift des Vereines Deutscher Ingenieure*, vol. 53, p. 714, 1909.

‡ *Proceedings of the American Institute of Electrical Engineers*, vol. 27, p. 1027, 1908.

§ Watson, in his British Association paper, "Atmospheric Loss off Wires under Direct-Current Pressure," finds that $0{\cdot}2 + \frac{0{\cdot}8\, b}{760}$ expresses the relation more correctly, but as the variation in b is not very great, I neglect this correction.

I find that the following somewhat simpler expression represents fairly well the critical potential difference in virtual kilovolts—

$$KV = \frac{0{\cdot}115\,b}{0{\cdot}5 + r}\left(\frac{1}{1 + 0{\cdot}013\,v}\right) r \log \frac{s}{r}.$$

Here b is the barometric pressure in mm. of mercury, r is the radius of the wire in cm., s the distance between the two wires in cm., and v is Mershon's "vapour product"—namely, the pressure of saturated steam in mm. of mercury at the given temperature multiplied by the relative humidity, or the ratio $\frac{\text{actual moisture}}{\text{possible moisture}}$.

I have communicated this formula to Mr. Mershon, asking his opinion, and he writes as follows: "I find that your formula does not give quite as close results as mine, but I think perhaps the results it does give are as close as the measurements would justify, and as it is somewhat simpler than my formula, it is perhaps preferable for practical use."

The protection of power lines against pressure surges due to atmospheric or other causes is a very important matter.

It is well known that the connection of an underground cable with an overhead line constitutes a special danger to the cable from atmospheric discharges. Already in 1890 Sir Oliver Lodge has shown in his paper* on "Lightning Guards for Telegraphic Purposes and the Protection of Cables from Lightning," that the lightning discharge is of an oscillatory character, and that protection may be obtained by the use of choke coils and condensers. The application of the principles of protection announced by Sir Oliver Lodge about twenty years ago has since that time become quite common in telegraph work, but for the protection of power cables it has, as far as I know, first been put into practice by Mr. G. Semenza, of Milan. Originally, a large amount of the power required in the town had been brought from Paderno by overhead line right up to the sub-station in Porta Volta, but owing to the growth of the town it had been found necessary to stop short with the overhead line some distance outside Milan and use cables for the approach to the sub-station. Since the power for lighting, tramways, and industrial purposes has mainly to be transmitted through these cables, their protection is a matter of vital importance, and has been provided for by a kind of gigantic Faraday cage surrounding the point where the overhead lines are connected to the cables by transformers. The transformers, switches, lightning protectors, and accessory electrical appliances are placed in a large building which acts in the manner of a Faraday cage. The iron parts of the structure are earthed, the roof and the window-frames are of iron, and under the plastering of the walls there is iron netting. A direct metallic connection between the overhead line and the cage would, of course, give absolute protection to the contents and the cable, but this would be inadmissible, as thereby the whole of the lines would be earthed.

* *Journal of the Institution of Electrical Engineers*, vol. 19, p. 346, 1890.

The problem then was to find an arrangement which would give the protection of a direct connection without actually making it. This problem Mr. G. Semenza * has solved in an ingenious manner by making use of resonant circuits. The frequency of a lightning discharge may be anything between 20,000 and 10 millions. If, then, a capacity and inductance tuned to any of these frequencies are placed in series and connected to line and cage, a current of that particular frequency will flow to earth as if the connection were direct. Even if the frequency were only approximately that to which the set was tuned, the reactance would not be excessive and the protection would be sufficient. Thus a set tuned to 1 million frequency would at 10 million frequency have a reactance of ·158 ohms and at 100,000 frequency a reactance of 165 ohms. A set tuned to 100,000 frequency would at 20,000 frequency have a reactance of 192 ohms. A set for 1 million frequency may conveniently be formed of two Moscicki condensers in parallel, having together a capacity of 0·01 mf. and an inductance of 2·54 microhenry. The latter is obtained by two turns of 2 mm. copper wire 50 cm. in diameter. A set for 100,000 frequency would require 8 condensers in parallel and a coil of ten turns. For the ordinary working frequencies up to 50 either set has of course a practically infinite reactance, that is to say, it has no effect on the power current. The Milan transmitting station has been at work now for about two years with perfect success. It should be noted that the system not only protects against lightning discharges, but against any abnormal rise of pressure, in so far as this is caused by a high-frequency surge.

Whilst on the subject of safety devices in connection with power transmission, I must refer to another recent invention, the object of which is the prevention of the infiltration of high-pressure current into low-pressure lines. That such a device is urgently needed is shown by the lamentable accident which happened last August in Olgiate, where several persons were killed by contact with nominally low-pressure lighting circuits. The danger of a short or a leak between high- and low-pressure circuits does not lie in the transformer. This can be made absolutely safe; but the switches and leads to the transformer, and especially the outside lines where there are miles of them, are a source of danger. A broken wire or a branch of a tree blown across two lines by the wind are possibilities from which no excellence of workmanship can guard us. Some means should therefore always be provided to cut off the current automatically in the low-pressure circuit as soon as its potential to earth exceeds a predetermined limit. Such an instrument was perfected last year by Mr. Arcioni, of Milan, and is now being gradually taken up on the Continent. The essential parts are three electromagnets with shaded poles connected star fashion, with the centre point earthed, to the three wires of the low-pressure system. In front of the poles are the three legs of a star disc mounted on a counterweighted spindle. As long as the three wires have normal

* *Atti dell' Associazione Elettrotecnica Italiana*, vol. 12, p. 585, 1908.

potential difference to earth the torque exerted by the shaded poles is insufficient to raise the weight, but if through infiltration of high pressure the electrical centre is displaced the torque increases, the weight is raised and makes contact in a relay circuit, which then trips the main switch. If the weight is adjusted to rise at double normal torque the apparatus also acts if one of the low-pressure wires should go to earth. Last year I tested the Arcioni safety device on the Milan system, making artificial leaks from the 6,000-volt network to a local secondary lighting circuit, and found the action absolutely reliable.

The commercial development of electric power distribution on a large scale in this country by companies established for this purpose may be said to have begun with the present century. The supply of power current from central stations is of course much older, but these undertakings, whether private or municipal, are working under "provisional order," and are supplying electricity over restricted areas for lighting and other purposes, power included. If customers are found ready to take large parcels of power they are a welcome addition to the general business, but it is not the main object with which the central station has been started. I exclude therefore such works and confine my attention to companies who work under so-called "Power" Acts, and whose main object is to supply power in large parcels to important industrial undertakings within a wide area. Of such companies there are now over a dozen at work in this country, and in the Appendix I give a list of the most important of them. So far as I have been able to obtain them, I also give particulars as to the character and capacity of the power stations, the system of transmission, the greatest distance to which the current is transmitted, the total kilowatt connected, and the nature of the industries using electric power. The public generally, and even some engineers, are still under the impression that a country of abundant water power offers better opportunities for electric power distribution than a country of cheap coal, but that this is in reality not so is demonstrated by the great development which power supply has reached in this country. In the country of waterfalls industries have to be introduced in order to utilise the power made available through electric transmission, whilst in the coal country highly developed industries of different kinds are already there. As regards capital outlay the advantage lies generally with the thermal station, quite apart from the extra cost of a steam reserve, which, for at least part of the power, in many cases is unavoidable. This drawback may be compensated by a very high load factor, such as is obtainable when the current is used in electrochemical processes, but with the load factor ruling in other industries the energy costs less in the country of cheap coal than in the country of abundant water power. If, then, we speak of the cheap water power of Swiss and Italian hydro-electric works, we do not mean that those works can produce power more cheaply than English thermal stations, but that they can produce it more cheaply than if they had to use imported coal.

Although in this country we have only little water power, the deficiency is made up by other sources of energy which now mostly run to waste. Mr. C. H. Merz, in an admirable paper read before the Iron and Steel Institute,* pointed out that within the area served by the North-East Coast Power System (Companies 1, 3, and 9 in the Appendix), the gas obtained as a by-product of the coke ovens could be made to yield continuously 150,000 H.P. if burned under boilers, and 250,000 H.P. if used in internal-combustion engines. It is the merit of Mr. Merz to have recognised the enormous commercial importance of these sources of energy, and to have already made a beginning with their utilisation by the establishment of what he calls "waste heat stations." At the date of the paper the three companies had at work five such waste heat stations, three in connection with coke ovens and two in connection with blast furnaces. The main generating stations and the waste heat stations are all linked up to a common network, so that all the current produced by the latter is utilised and the main stations only supply the amount required to make up what is wanted to satisfy the demand existing at the time. No spare plant is required at the waste heat stations, and irregularities in their output, or even the shutting down of one or the other altogether, has no effect on the general supply. An essential part of this system of working is the linking up of all generating stations into one common network. This necessitates the employment of some safety device by which a faulty cable is automatically detached, for otherwise a short or heavy leak in any single cable would influence and might possibly put out of action the whole system. Such a safety device has been introduced by Messrs. Merz and Price.† At each end of a section current transformers are inserted with their secondaries coupled in opposition by a pilot cable. As long as the main cable is in perfect order the currents flowing through the primaries of the transformers at either end are equal and no current flows in the pilot cable. If, however, a leak or short occurs anywhere in the main cable this balance is disturbed and the pilot cable receives current which works switches at both ends, so that the faulty section is automatically and instantly cut out, leaving the rest of the system unaffected.

Electric Railways.

The use of electricity for the propulsion of trains is so wide a subject that I am compelled to restrict my remarks to its latest phase, the use of alternating currents. I am quite aware that there are some enthusiastic adherents to the direct-current system who recommend working main lines by overhead wire at some 3,000 volts, but the majority of practical men hold that alternating current in some form or other must be the means to supply power to the

* *Journal of the Iron and Steel Institute*, 1908, part 3, p. 81.

† *Elektrotechnische Zeitschrift*, vol. 29, p. 331, 1908.

traction motor. The only question on which there may still be difference of opinion is whether the current shall be 3-phase or single-phase. Electricians prefer the former, railway men the latter mainly on account of the greater simplicity of the overhead work. As the railway men are in reality the customers who give the order to the electrical engineer, it seems likely that the single-phase system will be the one more generally adopted; and indeed a very respectable beginning has within the last four years already been made on the Continent. From detailed tables kindly supplied to me by two of the largest electrical engineering firms in Germany, namely, Messrs. Siemens-Schuckert Werke and the Allgemeine Elektricitäts Gesellschaft, I find that each has up to the present either supplied or on order single-phase electric motor coaches and locomotives aggregating, on the 1-hour rating, over 50,000 H.P. Compared to these figures our own achievements in single-phase traction look rather small. Beyond the Morecambe-Heysham line, which has been in successful operation for some time, and the Victoria-London-Bridge line which is about to be completed, we have nothing to show in this direction.

In Italy considerable progress is also being made. The Government have decided to electrify eleven sections on the State Railways, aggregating 337 miles of track, but on the 3-phase system. Thus the battle of the phases is still undecided. The decision of the Italian State Railways to use 3-phases, whilst in Germany, Austria, England, Sweden, and America the single-phase system is preferred, is highly interesting. I have asked Mr. Verola, the Chief Engineer of the Electrical Department of the Italian State Railways, what were the reasons for this decision, and he has been good enough to give them. The following is the substance of his letter :—

> "The decision to use the 3-phase system is not final and absolute for our administration, but the latter considers it preferable as a beginning for the lines at present under electrification. The possibility to use the single-phase system in other cases, which may better lend themselves to it, is thereby not excluded. In the case of the three lines (Pontodecimo-Busalla, Bardonecchia Modane, and Savona-Ceva) which are about to be opened, the service is extremely heavy, trains of 400 tons and over having to be hauled up on long grades of 25 to 35 per cent. at a speed of 45 km. per hour. With the 3-phase system it is possible to comply with these conditions by using two locomotives. These weigh each 60 tons, and develop each at the 1-hour rating 2,000 H.P. They have five driving axles and two motors, which are placed above and between the three middle axles. Connecting rods transmit the motion from the motor to the driving axles. The 3-phase system has the advantage that in running downhill the speed cannot exceed a certain limit, whilst recuperation of energy is possible. With the single-phase system the weight

of the motors would be at least doubled, resulting in a greater expenditure of energy, more especially as we shall be obliged always to use two locomotives to each train. The advantages of wider speed adjustment in running and better efficiency in starting are not of importance, since the grades are long and fairly uniform, and the distance between stations is great, whilst the latter are all on the level. For these reasons, and also on account of uniformity in the service, it is probable that also some future electrifications will be on the 3-phase system, notably that of the prolongation of the Valtellin line to Milan, which will shortly be taken in hand. It is, however, highly probable that some other lines will be worked single-phase. One of these is the line Turin-Pinerolo-Torre-Pelice, where widely different speeds are necessary, the maximum being 80 km. per hour for 100-ton passenger trains."

I have given the substance of Mr. Verola's letter at some length, as it appears to me an admirably clear and unbiassed statement regarding the relative advantages of the two systems.

In Switzerland the Federal Government appointed some years ago a committee of electrical and railway engineers to report generally on the question of electrifying the Swiss railways. The first report * dealt with the amount of power required, and urged the Government to secure water-power rights in time. The average power was estimated at 100,000, and that at peak time at 500,000 H.P. In a second report * some standards as to weight and speed of trains, acceleration, horse-power required in starting and running, time interval between trains, and other matters connected with the future electrical service were suggested, whilst a third report dealt with the question of a standard frequency; but on the question whether the single- or the 3-phase system is to be chosen the committee has not yet pronounced an opinion. From private conversations I have had with Swiss railway men, I incline to the belief that the decision will be in favour of the single-phase system, especially since by the use of the Deri type of motor it has been found possible greatly to simplify and also lighten the accessory equipment. The first test of this motor for traction was made on the 3-phase Engelberg railway, 1 phase only being used. No resistances, auto-transformer, contactors, regulating switches, or controllers of the usual construction are required. The starting and the regulation of the tractive force and speed is effected simply by shifting the brushes. Thus all the driver has to do is to attend to a hand-wheel, whose motion is transmitted to the brush rockers by positive mechanical gearing. A glance at the diagrams, Figs. 6 and 7, will show how great is the simplification of equipment resulting from the use of the Deri motor instead of the ordinary compensated series motor. Fig. 6 shows the equipment of the motor coaches on the Seethalbahn running from

* *Mitteilungen der Schweizerischen Studienkommission*, Nos. 1 and 2.

Lucerne to Wildegg, a distance of 59 km. This line has been electrified by Messrs. Brown-Boveri, to whom I am indebted for the diagrams. Fig. 7 shows the equivalent equipment worked out by the same firm for Deri motors.

I have mentioned a moment ago that the Swiss committee has come to a conclusion as regards a standard frequency.* Comparative estimates made for 15 and 25 periods and for single-phase working have shown a saving for the lower periodicity for the rolling stock and line as regards weight and cost, but an increase as regards generating and transforming plant. On the whole the balance is slightly in favour of the lower periodicity, and as this has also been already adopted in the South of Germany and in Italy the committee recommends 15 periods as a standard, with a latitude of 10 per cent. up and down. This latitude is recommended in order to give existing power works, whose frequency lies generally between 40 and 50, an opportunity to supply traction current by means of frequency changers having a ratio of 3 to 1. Thus a works supplying its other customers with current at 50 periods would supply the railway with current at $50/3 = 16\frac{2}{3}$, and a 40-period station could supply current at $13\frac{1}{3}$ frequency.

Winding Engines and Rolling Mills.

I take these two subjects together because the conditions under which electric driving is applied in both cases are more or less similar. Not only is the average demand for power large, but the maxima are large as compared to the average; the demand is intermittent; the pauses are short; the motion has to be reversed very quickly, and the torque the motor has to exert is at times very large. To meet these requirements many special systems have been devised, but all of them make use of two broad principles, namely, the use of a flywheel as a store of energy, and some means whereby the direct-current voltage supplied to the armature of the motor may be varied without sensibly diminishing the tótal power supplied to the armature. In some early applications of electricity to winding engines secondary batteries have been used as store of energy instead of a flywheel, but the cost of these, and the difficulties of keeping the contacts of the tapping-off switches in order, have prevented a general introduction of this system. Dynamic storage in some such way as first applied by Ilgner to winding engines, and voltage regulation on what may broadly be called the Ward-Leonard system, have made it possible to satisfy the very severe conditions under which winding engines and rolling mills have to work. In some special cases winding engines are driven direct by 3-phase motor, but the motor to which a reversing rolling mill is mechanically coupled is necessarily a direct-current machine. The motor which supplies power to the variable-voltage generator may be either a direct-current or an alternating-current motor. To make the flywheel effective there

* *Mitteilungen der Schweizerischen Studienkommission*, No. 3.

must be speed variation. Where the original source of power is continuous current, this is, of course, easily obtained without loss of energy. Where 3-phase current is the source of power the usual method is to employ a slip-ring motor and some automatic device for inserting and withdrawing resistance in the rotor circuit, but this means some loss of energy, and for this reason the speed range of the flywheel is generally made smaller than with a direct-current plant. It is, however, possible also in the case of 3-phase plant to avoid the loss of energy in regulating resistances by adopting some kind of cascade working. Such an arrangement has been worked out about a year ago by Messrs. Brown-Boveri. The variable rotor resistances are replaced by a direct-current armature working in a 3-phase stator, and the power developed mechanically by this armature may either be added mechanically to that of the 3-phase motor, or electrically to the supply circuit. In the latter case an additional generator is, of course, required. A good example of modern English practice in direct-current rolling-mill electrification is the plant supplied by the Electric Construction Company, Ltd., of Wolverhampton, to the steel works of Sir Alfred Hickman, Ltd., of Bilston. The makers have given me the following particulars: The flywheel set consists of a 2,000-H.P. direct-current motor, two 28-ton flywheels and two generators capable of giving any voltage between −1,000 and +1,000 volts. The excitation of the motor is adjusted automatically so as to produce a speed variation of the flywheels between 290 and 350 revs. per minute. The energy given out when dropping from the higher to the lower speed is 46,000-H.P. seconds. This set supplies power to a cogging and a barring mill. The cogging mill motor works a 30-in. mill, and when cogging down ingots of 3 tons weight has to develop 4,800 H.P., and for 2-second periods once an hour 9,600 H.P. The barring mill motor works a 24-in. mill, and has to develop 6,000 H.P., and for 2-second periods once an hour, 12,000 H.P. The maximum speed is 120 revs. per minute, and the time occupied in reversing from maximum speed in one direction to that in the other direction is 6 seconds. As an example of a reversible mill driven by 3-phase current I take that supplied by the British Thomson-Houston Company, Ltd., to Messrs. Dorman, Long & Co., Ltd. It is a cogging mill with rolls 28-in. centres, and the normal speed is 70, the maximum speed 90 revs. per minute. The flywheel set consists of a 3-phase 950-H.P. non-synchronous motor, coupled to a 1,000-k.w. 400-volt direct-current generator and a 30-ton flywheel. The speed limits are 400 and 480 revs. per minute, and the maximum peripheral speed of the flywheel is 295 ft. per second. The mill motor is rated at 1,200 H.P., and has an overload capacity for short periods of 3,600 H.P. The time required for reversing from full speed in one direction to full speed in the other direction is 4 seconds. The mill deals with 1,800-lb. billets 12 in. square, reducing them to 3-in. square bars in 14 passes. The output is 15 tons per hour.

It would be interesting and useful to have statistics of all the

winding engines and rolling mills which in this country are electrically driven. Unfortunately I am not able to present you with such statistics, but in the Appendix I give the data I have been able to collect. For the list of rolling mills in Appendix III. I am indebted to Mr. J. F. C. Snell, for the table of winding engines (Appendix IV.) and the second list of rolling mills (Appendix V.) to the makers, Messrs. Siemens Brothers. In Germany the electrification of rolling mills has gone hand in hand with the development of the internal combustion engine, working with coke-oven or blast-furnace gas. From a list sent me by Messrs. Erhardt and Sehmer, in which particulars are given of those gas-engine-driven dynamos which supply current to iron and steel works, I find that a little over 50,000 H.P. has been installed by this firm alone. The largest unit is 2,300 H.P., and the average is 1,460 H.P. Since similar plant is also supplied by other makers, the total horse-power used in Germany in electrified rolling mills and other heavy machinery in iron and steel works may be estimated at considerably over 50,000 H.P.

Electric Steel Furnaces.

The reduction of iron ore by heat applied electrically has not yet advanced much beyond the experimental state. A plant for the electric production of iron direct from the ore has been erected in Domnarfvet, Sweden,* but the production is only about 6 tons a day. In external appearance the furnace resembles an ordinary blast furnace, but on a small scale. The heat is produced in the lower part between three carbon electrodes supplied with 9,500 amperes 3-phase current at 60 frequency. The electrodes project through the roof of the smelting chamber; the brickwork being hot is to a certain extent conducting, and to avoid loss of current by contact between the electrodes and the brickwork the latter must be kept cool in the immediate neighbourhood of the electrodes. This is done by passing the gas collected from the top of the furnace, which is comparatively cool, through the annular space between the brickwork and the electrode. The gas is circulated by an electrically driven fan. No air is admitted into the furnace, so that no combustion takes place within the furnace, and the consumption of coke is restricted to the quantity required for the reduction of the ore, say about one-third of a ton to the ton of pig produced, as against 1 ton in the case of an ordinary blast furnace. Thus the saving of two-thirds of a ton of coke represents the commercial advantage of electric reduction of ore, and against this must be set the cost of energy. This process could only be successful in a country where electrical energy is exceedingly cheap and fuel very dear.†

When we come to the manufacture of steel from pig or the refining of steel the outlook is far more hopeful; in fact, the experimental stage

* E. J. Ljungberg, *Journal of the Iron and Steel Institute*, 1909, part 2, p. 10.

† In the Engineering Supplement of the *Times* of November 3rd, it is stated that both in Canada and Sweden plant for the electric reduction of iron ore on a large scale is about to be erected.

has long been passed and the practical results obtained are eminently satisfactory, not only in a technical, but also in a commercial sense. Even where owing to the price of power the electric process is no cheaper than the thermic process, the former enables the steel refiner to achieve results with certainty and regularity which under the old methods are hardly attainable at all, or only, so to say, by good luck.

In the furnace electricity is merely used to produce a large amount of heat locally; there is usually no electrolytic action. All furnaces are worked with alternating currents, the heat being produced either in an arc or by the passage of the current through the metal itself. It is just thirty years ago that the late Sir William Siemens patented an electrically heated crucible. The arc was formed between the metal in the crucible and a water-cooled electrode projecting downwards through the cover. This principle is still adhered to in the modern arc furnaces. In the Girod furnace water-cooled steel blocks let into the bottom of the hearth form one electrode and heavy bars of carbon let

Charge in Tons.	Kilowatt-hours per Ton of Steel.	
	Cold Charge.	Molten Charge.
1	1,130	500
2	1,005	400
3	940	360
5	860	340

down from the top through openings in the roof the other. In the Herault furnace there are two arcs in series, the current passing from one electrode to the bath and from the bath to the other electrode. In the Stassano furnace a 3-phase arc is employed, the electrodes being three inclined carbon rods projecting through the walls of the furnace to a point in the centre slightly above the level of the bath. In all these cases extremely high temperatures (up to 1,800° C.) are produced in a restricted space and the heat is carried to the rest of the bath by circulation of the molten metal. The amount of energy required per ton of steel produced varies naturally with the capacity of the furnace, the quality of the charge and that of the steel produced, and also with the temperature of the charge. If the latter is introduced cold and has therefore to be first melted before the refining process can commence, more energy is required than where the electric furnace is charged with molten metal from a Bessemer converter or Martin open hearth. From a number of recent publications * on the subject it

* Clausel de Coussergues, *Revue de Metallurgie*, June, 1909, pp. 589–678; J. B. C. Kershaw, *Cassier's Magazine*, vol. 36, pp. 237–249, 1909; J. Kollmann, *Technik und Wirtschaft*, May, 1909, pp. 193–206.

would appear that all three furnaces are in point of energy consumption approximately equal. For a capacity of 2 to 3 tons the average requirement per ton of finished steel is about 1,000 k.w.-hours when the charge is introduced cold, and about 400 k.w.-hours when it is introduced in a molten state. Smaller furnaces require more and larger less energy. Thus curves given by Eichhoff * for the Herault furnace show the relation, given in the table on page 31, between charge and energy.

A drawback inseparable from the employment of electric arcs is the great fluctuation in the load, making it impossible to work an arc furnace from a circuit which supplies other consumers. This difficulty is overcome with the so-called "induction furnace," where the heating is by ohmic resistance. The term "induction furnace" has been given to this type because the heating current is generated by induction in the metal bath itself. In 1885 Mr. Ferranti had already patented this method of applying heat by means of an iron-cored transformer, the primary of which received power from an alternator whilst the secondary was formed by a closed circuit of the metal to be heated. It was, however, only in the beginning of this century that the principle has been applied on a large scale by Kjellin to steel furnaces. Considerable improvements in details have been introduced into this furnace within the last three years, the new type being known as the Roechling-Rodenhauser furnace. The transformer is of the core type, and the secondary circuit is formed of the central portion of the hearth lying between the two limbs and narrow channels surrounding them on the outside. Owing to the restricted area of these channels the current density in them is much greater than in the central hearth and the production of heat correspondingly greater. To increase the heat given directly to the hearth additional current is sent through the latter from a low-tension winding on the transformer.† The electrodes are cast steel plates embedded in the refractory lining of the furnace. When hot the refractory material becomes a conductor, and thus the current from the low-pressure winding of the transformer is passed through the central part of the hearth in addition to the current induced in the bath itself. It is, of course, quite feasible to use 3-phase current, in which case a 3-phase transformer of the core type is employed. Mr. Rodenhauser in the paper quoted points out that the 3-phase furnace is preferable, since the generating plant for equal power is cheaper if the power is supplied in the shape of 3-phase as against single-phase current. Generally the furnace is charged with molten metal, but if it is to be used for fusing a cold charge, closed iron rings are placed at the bottom of the grooves. These act as short-circuited secondaries, and becoming fused establish metallic continuity throughout the solid particles of the charge. These are in turn fused, and after some time the whole mass is liquefied. Since the inductive drop of

* *Revue de Metallurgie*, June, 1909, p. 666.

† W. Rodenhauser, "The Electric Furnace and Electrical Process of Steel Making." *Journal of the Iron and Steel Institute*, 1909, part 1, p. 261.

transformers increases with an increase of linear dimensions, and decreases with the frequency, it follows that the larger the furnace the lower must be the frequency. In the original Kjellin furnaces of the largest size as low a frequency as 5 per second has been employed, but Mr. Rodenhauser claims that with his type of furnace, in which by a more favourable disposition of the primary coil and the channels of the bath the magnetic leakage has been considerably reduced, the ordinary motor frequency of 25, and in smaller furnaces a frequency as high as 50 may be used. This is an advantage in so far as the furnace may be worked from existing circuits. The energy required per ton of steel is given by Kollmann * as 125 k.w.-hours for rails and 250 k.w.-hours for tool steel, the charge being in both cases introduced in the molten state.

The electric furnace for steel making and steel refining is now an important accessory in steel works, and thousands of tons of steel are produced annually, both in furnaces of the arc and in those of the induction type. Mr. Kershaw, in the article cited above, states that in England and the Continent there are between thirty and forty such plants in regular commercial operation, and gives a list of the more important steel works using electric furnaces.

Fixation of Atmospheric Nitrogen.

Of the many methods devised for fixing atmospheric nitrogen with the object of producing a fertiliser to replace Chili saltpetre, I can only refer to three which have attained considerable importance. This restriction is the more justified as the subject has a little over a year ago been brought before you in a paper dealing with a variety of processes.† The two methods to which I refer here are—

1. The Birkeland-Eyde system, first introduced in Norway.‡
2. Frank-Caro system, first introduced in Italy.§
3. The Schoenherr and Herzberger Process.

The Birkeland-Eyde electric arc furnace is so well known that I need not enter into a technical description, but it is important to note that the operations of the Norwegian Nitrogen Company are now carried on on a very large scale. The Notodden factory, fitted with four 7,000-k.w. generators and 32 furnaces, has a yearly production of 20,000 tons of nitrate of lime, and a second factory on the Rjukan Fall is in course of construction. It is expected to be in working order in 1911, when the yearly production will be increased to 100,000 tons. The process is entirely electrical in the sense that no fuel of any kind is used, the heat required for steam raising and other purposes con-

* *Technik. und Wirtschaft*, 1909, pp. 193–206.
† Cramp and Hoyle, "The Electric Discharge and the Production of Nitric Acid," *Journal of the Institution of Electrical Engineers*, vol. 42, p. 297, 1909.
‡ Eyde, *Journal of the Royal Society of Arts*, vol, 57, p. 568, 1909.
§ Erlwein, *Elektrotechnische Zeitschrift*, vol. 28, p. 41, 1907.

nected with the process being obtained as a waste product from the electric furnaces.

The Frank-Caro process is not, strictly speaking, electrical, yet it has only become commercially possible by the aid of electricity. The raw materials for this process are calcium carbide and nitrogen, the former being produced by electricity in the well-known way, and the latter by liquefying air in a Linde machine and subsequent fractional distillation. The carbide is brought to glowing heat in a closed, externally fired retort, and the nitrogen passed through. Dr. Erlwein gives the following formula for the reaction—

$$CaC_2 + N_2 = CaCN_2 + C.$$

Two tons of carbide are required to produce half a ton of fixed nitrogen in the shape of calcium cyanimide, and since in a well-organised carbide works 1 k.w.-year is required for the production of 2 tons of carbide, Dr. Erlwein claims an output of half a ton of fixed nitrogen per kilowatt-year. No figures as to the energy required per ton of nitrogen in the Notodden works are available, but, taking the figure of 900 kg. nitric acid per kilowatt-year given by Messrs. Cramp and Hoyle as correct (Erlwein gives 700 kg.) for the arc furnace, it would appear that the indirect electrical process yields for the same expenditure of energy more than twice as much fixed nitrogen as the direct process. Against this it must, however, be remembered that in the indirect process coal is consumed, not only in the preparation of the carbide, but also for heating the retort, whilst some energy left out of Erlwein's calculation is required in working the Linde plant. A comparison of the two methods merely on the ground of yield of nitrogen per kilowatt-year would therefore be misleading. The Frank-Caro process has been first established in 1905 by the Italian Nitrogen Company in Piano d'Orta. The works were started with an output of 4,000 tons annually, and this has now been increased to 20,000 tons. Works on the same system have been or are being erected in Sebenico, Briançon, Martigny, and other places.

The latest process* for the production of nitrous compounds, is the invention of Messrs. Schoenherr and Heszberger, and is being introduced on a large scale in Norway by the Badische Anilin und Sodafabrik. In this process air is passed through an iron tube in which an alternating-current arc of 5 metres length is maintained under a pressure of 4,200 volts. The air enters one end of the tube by a series of tangential holes, and the rotary motion thus produced keeps the arc confined to the axis of the tube. Each arc absorbs 600 H.P. The inventors claim a greater yield of fixed nitrogen than is obtainable under the Birkeland-Eyde method, and a compound richer in nitrogen—namely, 18 per cent. against 13 per cent. The owners of the patents who have pooled their interests with the Norwegian Nitrogen Company propose to erect large works in the western parts of Norway, utilising about 400,000 H.P.

* Schoenherr, *Elektrotechnische Zeitschrift*, vol. 30, p. 365, 1909,

ELECTRICITY IN AGRICULTURE.

It is not necessary to refer in detail to the use of electric motors for driving agricultural machinery on the field and in the farm, but it might be of interest to glance briefly at a new development in the application of electricity for the promotion of the growth of plants. The discovery that electrification of the atmosphere immediately above the plant stimulates in certain cases its growth is already thirty years old, but only recently has this idea been practically developed—first by Professor Lemström in Sweden, and more recently still by Sir Oliver Lodge, in collaboration with Mr. J. E. Newman and Mr. R. Bomford, on an experimental farm at Bitton, Glos., and on a farm of about 40 acres at Evesham, near Birmingham, and at other places. A network of galvanised iron wires is stretched over the field to be treated and suspended 18 ft. from the ground from wooden posts and oil insulators. The posts are placed 70 yards apart, so that about one post per acre is required. The network consists of No. 11 S.W.G. wire placed over the posts in parallel rows 100 yards apart, and No. 20 S.W.G. wire cross-connecting the stouter wires every 10 yards. The attachment of the latter to the insulators is not direct, but by means of short links and tension insulators to reduce the electrical stress on the insulator itself. The network is positively electrified to from 60,000 to 100,000 volts by means of an induction-coil mercury gas break and Lodge rectifying vacuum valves. The induction coil is worked on the primary side by continuous current obtained from an ordinary dynamo. Mr. Lionel Lodge, who is the electrical expert for the various installations, informs me that there is no difficulty in keeping the potential in the network up to the figures given except in misty weather or during rain, when it may fall as low as 20,000 volts; also that the amount of primary power required per acre is very small, namely, from 10 to 20 watts. The installation is run for five or six months during eight to ten hours each day, and the total expenditure of energy is only about 20 B.O.T. units per annum per acre. Under this treatment the increase in the yield per acre is about 30 per cent., but under certain conditions it may be even more. The system is in use on several farms in this country, on six farms in Germany, and on one farm in Holland.

In the time at my disposal I have only been able to refer to a few of the industries which have benefited by the application of electricity; but when one reflects that nearly every industry in the country has been, or might be, furthered by the use of electricity in one form or another, one comes to see that an enormous field of useful work is open to the electrical engineer—not only useful to himself, but even more so to the interests that employ him. How, then, comes it that electrical engineering is not as prosperous as it might be? Some of our members say, because we are backward as compared with our foreign competitors. If by that term they mean that our electrical engineering works cannot produce equally good plant as our rivals, I

disagree. I have frequently visited Continental shops, and, although I am quite willing to admit that excellent work is done there, I am also convinced that British shops can turn out work equally well and generally at a slightly lower prime cost. There is certainly no justification in reproaching the makers of electrical plant with backwardness; and, moreover, it is bad business policy. If, however, the reproach is levelled against the potential users of such plant there is some justification, and also a reason. Our great staple industries are old-established and have been fairly prosperous for generations; those on the Continent are of recent growth, and had to struggle into existence against English competition. To become successful they had to adopt every improvement which science put at their disposal. With them the application of electricity is almost a vital matter; with us only a desirable improvement. Is it, then, to be wondered at if a works manager or owner, who has grown up in the pre-electric days, and has been doing a prosperous business ever since, should be rather slow in embarking in new methods of working which, to his thinking, might entail the possibility of risk and the certainty of greater mental exertion? There are, of course, exceptions; and a good many of them, as witnessed by the great strides which electrical methods applied to our staple industries have already made; but, compared to what the development might be, we must admit that we have as yet only touched the fringe of this vast field. There is progress, but it is not fast enough, and to accelerate it we must educate the potential users of electrical plant. A beginning in this direction has already been made by the managers of electric light stations. They are educating the householder by local exhibitions and literature that he can understand. On the Continent every large electrical engineering firm has a literary department whose business it is to educate possible customers. No sooner is a new winding plant started, or a cotton mill electrically equipped, than well-written, well-printed, and beautifully illustrated leaflets are sent out into the world to tell possible clients of the work done by the firm. Here, such literary departments are the exception; and thus it comes about that we hear so much about the great advances made on the Continent and so little about equally good work done here.

Our Institution can also do something to accelerate the introduction of electricity into our great industries. It is no doubt very useful if we in our meetings read highly technical papers, and thus educate each other; but this is only part of our work. The other part is to educate the customer, and for this purpose we possess in our organisation of Local Sections the requisite machinery. By arranging for papers which shall be of interest to the particular industries carried on in the district of each Local Section, our Institution can further the adoption of electricity in these industries, and this will not only be to our own advantage, but even more so to the advantage of those whom we serve.

APPENDIX I.

LIST OF THE MORE IMPORTANT ELECTRIC POWER COMPANIES.

The Cleveland and Durham County Electric Power Company.
The Clyde Valley Electric Power Company.
The County of Durham Electric Power Supply Company.
The Derbyshire and Nottinghamshire Electric Power Company.
Fife Electric Power Company.
Kent Electric Power Company.
Lancashire Electric Power Company.
Midland Electric Corporation for Power Distribution, Ltd.
Newcastle-upon-Tyne Electric Supply Company, Ltd.
North Metropolitan Electric Power Supply Company.
North Wales Electric Power and Traction Company.
Scottish Central Electric Power Company.
South Wales Electrical Power Distribution Company.
Yorkshire Electric Power Company.

APPENDIX II.

CLEVELAND AND DURHAM ELECTRIC POWER, LTD.

1. Statutory Powers.—Cleveland and Durham County Electric Power Acts, 1901 and 1903.

2. Date when Supply Commenced.—1907.

3. Description, Capacity, and Voltage of Generating Stations and Plant.—Turbo-alternators, 3-phase, 40 cycles.

Grangetown.—Coal	Three 1,333 k.w. One 2,000 „		11,000 volts.
**Bankfoot.*—Waste heat ...	Two 1,500 „		2,750 „
**Weardale.*—Waste heat ...	Four 1,375 „		2,750 „
**Newport.*—Exhaust steam ...	Four 1,250 „ One 500 „		2,750 „
**Teesbridge.*—Exhaust steam...	One 1,125 „		2,750 „

4. Description and Voltage of Transmission and Distribution Systems.—Transmission and distribution, 20,000, 11,000, 2,750, and 440 volts underground and overhead.

5. Greatest Distance to which Power is Delivered.—About 15 miles.

6. Total Connections, Kilowatts.—24,400 k.w.

7. Nature of Industries Supplied and Horse-power of each Class :—

Iron works and rolling mills	5,238 H.P.
Iron mines	1,975 „
Machine shops	1,508 „
Salt works...	191 „
Flour mills	180 „
Shipyards	2,727 „
Miscellaneous manufacturers	3,343 „
Collieries	3,431 „
Bulk	5,467 „
Coke ovens	840 „
Dockyards...	1,907 „
Small motors, heating and cooking	905 „
Lighting	4,835 „
Total	32,547 H.P.

* These stations are owned by the Waste Heat and Gas Electrical Generating Stations, Ltd., but are operated by the Cleveland and Durham Company into whose network the current is delivered.

THE CLYDE VALLEY ELECTRICAL POWER COMPANY.

1. **Statutory Powers.**—To acquire lands, erect generating stations, and supply electricity within parts of the counties of Lanark, Stirling, Renfrew, and Dumbarton. The Burghs of Govan, Partick, Paisley, Port Glasgow, Hamilton, as also the City of Glasgow, are excluded except by consent. The Company possess certain powers for the laying of mains through Paisley and Hamilton. Other authorised undertakers are accorded the usual statutory protection. Company has power to pay interest out of capital for three years during erection of works.

2. **Date of Commencement of Supply.**—Yoker Station, August, 1905; Motherwell Station, January, 1906.

3. **Description, Capacity, and Voltage of Generating Stations and Plant.**—

Four 3,000 k.w. One 1,000 „ One 600 „	Westinghouse Parsons turbo-alternators, generating 11,000 volts, 3-phase, 25-period current, and the necessary exciters.

With the following plant:—

- Twelve Babcock and Wilcox double-drum water-tube boilers with superheated chain-grate stokers, conveying plant, bunkers, economisers, and feed pumps.
- Surface and barometric condensing plant with two cooling towers, natural draught type.

There is accommodation for 15,000-k.w. extensions at each station.

4. **Description, Voltage of Transmission and Distributing Systems.**—E.H.T. 11,000-volt mains are 3-core, paper-insulated, lead-covered, laid partly on the solid system and partly in ducts. Main ring cables, 0·15 sq. in. Transforming sub-stations and switch houses. Low-tension current supplied to consumers at 400 volts, 3-phase, 25 periods for power, and 230 volts between any phase and neutral for lighting. Low-tension cables are 4-core, lead-covered, paper-insulated, laid solid. Armoured cables are also laid in some cases. The Company have about 20 miles overhead transmission, high and low tension.

5. **Greatest Distance to which Power is Delivered.**—32 miles.

6. **Total Connections.**—19,000 k.w.

7. **Nature of Industries.**—

Ordnance works.
Steel works.
Shipbuilding yards.
Iron, steel, and other rolling mills.
Sheet mills.
Foundries.
Collieries.
Saw mills.
Tube works.
Chemical works.
Laundries.
Engineering works.
Bakeries, etc.

COUNTY OF DURHAM ELECTRIC POWER SUPPLY COMPANY.

1. **Statutory Powers.**—Acts 1900, 1906, and 1909.

2. **Date when Supply Commenced.**—1902.

3. **Generating Plant.**—This Company has no generating stations of its own, but obtains its supply in bulk from the Newcastle Electric Supply Company's system.

4. **Description and Voltage of Transmission and Distribution Systems.**—Transmission and distribution, 20,000, 5,750, 2,750, and 440 volts, 3-phase, underground and overhead. Also distribution at 600 volts and 480 volts (3-wire) for traction, lighting, and small motors.

5. **Greatest Distance to which Power is Delivered.**—About 15 miles.

6. **Total Connections.**—23,370 k.w.

7. **Nature of Industries Supplied and Horse-power of each Class.**—

Shipyards...	860 H.P.
Collieries	14,000 „
Engineering works	6,000 „
Iron works (rolling mills)	2,700 „
Chemical works	500 „
Rope works	660 „
Cement works	500 „
Flour and paper mills	3,100 „
Glass works	240 „
Stone and brick works	800 „
Miscellaneous (including small motors) ...	1,800 „
Total	31,160 H.P.

THE DERBYSHIRE AND NOTTINGHAMSHIRE ELECTRIC POWER COMPANY.

1. **Statutory Powers.**—*Area of Supply.*—The whole of the County of Nottingham, including the County of the City of Nottingham and the County of Derby, except that part of the County of Derby which lies to the south of the River Trent, and except that part of the said county which lies to the north-west of the boundary between Bakewell and Chapel-en-le-Frith.

To erect generating stations at Colwick near Nottingham, Warsop and Trowell near Ilkeston, also in parish and urban district of Newbold and Dunstan near Chesterfield.*

2. **Date when Supply Commenced.**—May 16, 1903.

3. **Description, Capacity, and Voltage of Generating Stations and Plant.**—One power house at Ilkestone in Derbyshire containing 1,450 k.w. of plant. Generating pressure 11,000 volts, 3-phase, and 500 to 600 volts direct current.

4. **Description and Voltage of Transmission and Distributing Systems.**—Underground cables (Callenders), transmission voltage (temporary), 3,000, reduced to 500 for customers. Supplies given in bulk.

5. **Greatest Distance to which Power is Delivered.**—4 miles at present.

6. **Total Connections.**—1,800 k.w.

7. **Nature of Industries in Company's Area.**—Collieries, iron works, brick works, hosiery and lace factories, engineering works.

* To acquire provisional orders. To purchase by agreement the tramways authorised by the Nottinghamshire and Derbyshire Tramways Act and the light railways authorised by the Newark and District Light Railways Order. Authorised capital, £1,800,000.

THE FIFE ELECTRIC POWER COMPANY.

1. **Statutory Powers.**—*Area of Supply.*—The County of Fife. Supply to authorised distributors in bulk, and for power to any person, and for lighting any premises on which power is used.

2. **Date when Supply Commenced.**—November, 1905.

3. **Description, Capacity, and Voltage of Generating Stations and Plant.**—2-phase 50-period 3,300-volt Willans Bruce Peebles generators. Capacity, 1,000 H.P.

Extensions now being put in: 2,000-H.P. Curtis turbine set, 6,600 volt, 3 phase, 50 period.

4. **Description and Voltage of Transmission and Distributing Systems.**—3,300-volt 2-phase armoured cables direct in ground. About 1 mile of overhead, 3,300 volt, 2 phase.

New plant now being put in: About 4 miles of 3-phase 6,600-volt overhead—6 wires and 3 miles under ground, 3-core paper, lead-sheathed cable laid solid.

5. **Greatest Distance to which Power is Delivered.**—About 7 miles where new plant is working.

6. **Total Connections.**—1,000 H.P.

7. **Nature of Industries in Company's Area.**—Collieries, brick works, bleach works, linen factories, etc.

Estimated horse-power in 2-mile radius...	...	10,000 H.P.
Estimated horse-power in 7-mile radius...	...	30,000 „

LANCASHIRE ELECTRIC POWER COMPANY.

1. Statutory Powers.—To supply electrical energy for power and lighting in so much of the County of Lancaster as lies south of the River Ribble and outside the boundaries of the City of Manchester and the county boroughs of Salford, Liverpool, Bootle, and Stockport, and so much of the county borough of Bolton as lies within 2½ miles of the existing Town Hall. The Company may only supply by consent in districts already served by a local authority or company.

2. Date when Supply Commenced.—August, 1905.

3. Description, Capacity, and Voltage of Generating Stations and Plant.—Plant consists of four 2,000-k.w. Curtis turbo-generators, generating at 10,000-volt 3-phase neutral-point earthed, surface condensers, Babcock boilers, natural and induced draught.

4. Description and Voltage of Transmission and Distributing Systems.—All feeders leave power station as bare copper conductors at 10,000 volts. About 60 miles underground feeder and 14 overhead. Transforming sub-station 10,000 to 400 volts on consumers' premises; 3-phase transformers used. Distribution, 400 volts for power and 230 volts (4-wire) for lighting; occasionally 3-phase converted to direct current for lighting; this incurs heavy losses and no advantages—on the contrary, distinctly disadvantageous.

5. Greatest Distance to which Power is Delivered.—About 12 miles.

6. Total Connections.—5,300 k.w.

7. Nature of Industries in Company's Area. Total Estimated Horse-power of each Class:—

Cotton spinning	500,000	H.P.,	approx.
Cotton weaving	250,000	,,	,,
Colliery industry	200,000	,,	,,
Paper making	10,000	,,	,,
Engineering	10,000	,,	,,
Calico bleaching, dyeing, printing, etc.	50,000	,,	,,
Miscellaneous	20,000	,,	,,
	1,040,000	,,	,,

MIDLAND ELECTRIC CORPORATION FOR POWER DISTRIBUTION, LTD.

1. **Statutory Powers.**—Provisional orders, etc., for following districts: Amblecote, Bilston, Brierley Hill, Blackheath, Brettell Lane, Compton, Cradley Heath, Darlaston, Finchfield, Great Bridge, Kingswinford, Lower Gornal, Lye, Ocker Hill, Old Hill, Penn, Princes End, Pensnett, Quarry Bank, Stourbridge, Tipton, Tettenhall, Willenhall, Wednesfield, Heath Town, Great Barr, Bushbury.

2. **Date when Supply Commenced.**—August, 1902.

3. **Description, Capacity, and Voltage of Generating Stations and Plant.**—Generating station contains Babcock and Wilcox boilers, Ferranti and Yates and Thom reciprocating engines, Ferranti alternators, Willans and Robinson Dick Kerr turbo-alternators. Total capacity of station, 10,000 H.P., generating at 7,000 volts, 2-phase.

4. **Description and Voltage of Transmission and Distributing Systems.**—Transmission at 7,000 volts, 2-phase to sub-stations. Local distribution at 2,700 volts, 2-phase, and 200 volts. Tramway supply at 500 volts continuous through rotary converters and motor-generators.

5. **Greatest Distance to which Power is Delivered.**—10 miles.

6. **Total Connections.**—7,685 k.w. at September 30, 1909.

7. **Nature of Industries in Company's Area.**—The industries supplied represent nearly every class of engineering, including tramway supply.

NEWCASTLE-UPON-TYNE ELECTRIC SUPPLY COMPANY, LTD.

1. Statutory Powers.—Acts 1900, 1902, 1903, and 1906, and a number of electric lighting orders.

2. Date when Supply Commenced.—Lighting, 1889; power, 1900.

3. Description, Capacity, and Voltage of Generating Stations and Plant.—All 3-phase, 40 cycles, 5,750 volts.

Carville	Six 5,000-k.w. turbo-alternators. Two 4,500-k.w. turbo-alternators.
Neptune Bank	One 1,800-k.w. turbo-alternator. Four 850-k.w. marine-type triple-expansion engines driving alternators.
Dunston (not yet running)	Two 8,000-k.w. turbo-alternators. One 7,000-k.w. turbo-alternator.

And several waste heat and other small generating stations.

4. Description and Voltage of Transmission and Distribution Systems.—Transmission and distribution 20,000, 5,750, 2,750, and 440 volts, 3-phase underground and overhead. Also distribution at 600 volts and 480 volts (3-wire) for traction, lighting, and small motors.

5. Greatest Distance to which Power is Delivered.—About 15 miles.

6. Total Connections.—Newcastle-upon-Tyne Electric Supply Company's own system, 37,880 k.w. Bulk supply to County of Durham Electric Power Supply Company, 23,370 k.w.

7. Nature of Industries in the Newcastle-upon-Tyne Electric Supply Company's Area. Horse-power of each Class:—

Shipyards	13,500 H.P.
Collieries	12,000 ,,
Engineering works	10,500 ,,
Chemical works	6,650 ,,
Rope works	1,000 ,,
Paint and lead works	950 ,,
Wood works	310 ,,
Potteries...	260 ,,
Miscellaneous, including small motors ...	5,340 ,,
Total	50,510 H.P.

NORTH METROPOLITAN ELECTRIC POWER SUPPLY COMPANY.

1. **Statutory Powers.**—North Metropolitan Electric Power Supply Acts, 1900–1909.

2. **Date when Supply Commenced.**—1904.

3. **Description, Capacity, and Voltage of Generating Stations and Plant.**—

Brimsdown.—5,000-k.w. steam-turbine plant, 11,000 volts, 3-phase, 50 cycles.

Willesden.—3,900-k.w. steam-turbine plant, 3,000 volts, 3-phase, 50 cycles.

1,500-k.w. transformer capacity stepping up to 11,000 volts.

1,950-k.w. steam generators, continuous-current, 500–600 volts.

The above stations are connected by two trunk mains 0·1 sq. in. 11,000 volts.

There are also two isolated generating stations :—

Hertford.—300 k.w.

St. Albans.—490 k.w. with continuous current, 460–560 volts.

4. **Description and Voltage of Transmission and Distributing Systems.**—

(1) 3-core paper cables (solid).
(2) Ditto, armoured.
(3) 4-core, armoured.

Standard Pressures:—

(1) E.H.T., 10,000–11,000 volts.
(2) H.T., 2,700–3,000 volts, 3-phase.
(3) L.T., 415–425 volts.

Supply given to authorised distributors at 1 and 2, and to individual power users at 3, on 4-wire system with 240 volts for lighting. Also at 500–600 volts generated direct or converted by rotaries or motor-generators to Metropolitan Electric Tramways.

5. **Greatest Distance to which Power is Delivered.**—Route length Brimsdown to Willesden is 21¼ miles, and there are branches off this main. Greatest distance power transmitted, 15 to 17 miles.

6. **Total Connections.**—About 10,000 k.w.

7. **Nature of Industries supplied in Company's Area. Kilowatts of each Class**:—

The Metropolitan Electric Tramways, 4,000 k.w., (plant installed).
Authorised distributors, 3,000 k.w. (maximum demand).
Power consumers supplied from trunk mains (lamp makers, flour mills, confectionery makers, etc.), 700 k.w. (maximum demand).

THE NORTH METROPOLITAN ELECTRICAL POWER DISTRIBUTION COMPANY, LTD.

Barnett Electric Lighting Order.	Enfield Electric Lighting Order, 1902. September, 1906.	Hertford Electric Lighting Act. November, 1901.	St. Albans and District Electric Lighting Act, 1907. October, 1908.
Two 100-k.w. induction motor-generators Two 300-k.w. La Cour converters supplied at 10,000 volts, 3-phase, 50 cycles	Two 100-k.w. ditto One 300-k.w. ditto	Three 100-k.w. steam sets	Two 150-k.w. steam sets in conjunction with dust destructor Two 95-k.w. Diesel sets
Direct-current 3-wire system, 2 × 230 volts	2 × 240 volts	2 × 230 volts (direct current)	2 × 230 volts (direct current)
1¼ miles	2 miles	1½ miles	1½ miles
Lighting, 380 k.w.	240 k.w.	350 k.w.	190 k.w.
Power, 145 k.w.	125 k.w.	60 k.w.	65 k.w.
Photo engravers, Dental works.	Mostly lighting, Saw mills, Engineers' shops, etc.	Mostly lighting	Printing, Hat making, Rubber manufacture.

THE NORTH WALES POWER AND TRACTION COMPANY, LTD.

1. **Statutory Powers.**—To construct electric works and to generate and supply electrical energy to authorised undertakers and to persons requiring a supply for power within an area of supply embracing the counties of Carnarvon, Denbigh (excluding Wrexham Borough and District), Merioneth, Anglesey, and certain parts of the County of Flint.

2. **Date when Supply Commenced.**—August, 1906.

3. **Description, Capacity, and Voltage of Generating Stations and Plant.**—Hydro-electric four 1,000-k.w., 10,000-volt, 3-phase, 50 cycles, head of water, 1,150 ft. Pressure, 500 lbs. per square inch; average rainfall in gathering ground, ½ in. per diem. Twin Pelton wheels by Ganz & Co., Buda Pesth. Alternators built by Bruce Peebles & Co., Ltd., Edinburgh. Exciters mounted on alternator shaft, 45 volts, 500 revs. per minute. Voltage control by Tirrill regulator within 1 per cent. variation; step-up transformers by Westinghouse, Trafford Park; two 500-k.v.a., 10,000/20,000-volts, 3-phase, 50 cycles. Switchgear by Ferranti, Ltd., Hollinwood; 10,000 and 20,000 volts.

4. **Description and Voltage of Transmission and Distributing Systems.**—Overhead bare wire transmission at 10,000 volts and also 20,000 volts. To sub-station transformed to 500/550 3-phase 50 cycle, for use in quarries, winding, ropeways, mills, compressors, pumps, etc. All overhead bare wires in quarries, except where used underground.

5. **Greatest Distance to which Power is Delivered.**—At present 14 miles. Extension proposed to 23 miles.

6. **Total Connections, Kilowatts.**—3,050 H.P. in quarries, also two 1,000-k.w. motor-generators at Aluminium Corporation Works, but not used at present owing to reconstruction of the Aluminium Corporation.

7. **Nature of Industries in Company's Area.**—Slate quarries only.

THE SCOTTISH CENTRAL ELECTRIC POWER COMPANY, FALKIRK.

1. Statutory Powers.—To supply electrical energy in bulk or otherwise for power and other purposes throughout the whole of the counties of Linlithgow and Clackmannan, and parishes of Logie, Stirling, St. Ninians, Airth Bothkenner, Larbert Dunipace, Denny Kilsyth, Falkirk, Slamannan, Muiravonside and Polmont in Stirlingshire, and the parish of Cumbernauld in Dumbartonshire—amounting to a total area of 460 square miles.

2. Date when Supply Commenced.—October, 1905.

3. Description, Capacity, and Voltage of Generating Stations and Plant:—

Bonnybridge Generating Station, near Falkirk.—System: Two-phase, 3,000 volts alternating, 50 periods.

Capacity.—2,000 k.w., comprising two 500-k.v.a. Bruce Peebles alternators coupled to Willans high-speed engines, and one 1,000-k.v.a. Bruce Peebles alternator coupled to Willans Parson steam turbine. Extension by 2,000 k.w. under immediate consideration. Lancashire boilers, hand fired. Steam, 200 lbs. pressure, superheated. Induced draught.

4. Description and Voltage of Transmission and Distributing Systems:—

Transmission System.—About 10 miles (route length) underground cable on the 2-phase system at 3,000 volts. Each feeder consisting of three paper-insulated, steel-tape armoured, concentric cables laid direct in ground. Two cables in service, the third remaining as a spare in case of breakdown of either of the others. One pole of each phase earthed at the generating station.

In addition to above, about 5 miles (route length) of overhead lines on the 3-phase system at 12,000 volts, star-connected with neutral earthed. Each feeder consisting of two 3-wire mains run in parallel. Connection is made to the old 2-phase system at convenient points by 3,000/12,000-volt step-up transformers Scott connected. All future extensions of any length will be on this system and overhead where possible.

Distribution System.—Strictly speaking, there is no distribution system, the transmission feeders being either looped or teed into H.T. transformer sub-stations on the consumers' premises. Some of the earlier consumers are supplied with 2-phase power at 440 volts; all the more recent consumers, however, when fed off the 2-phase system are supplied 3-phase at 440 volts by means of Scott connected transformers.

5. Greatest Distance to which Power is Delivered.—About 5 miles.

6. Total Connections.—1,300 k.w.

7. Nature of Industries in Company's Area. Total estimated Horse-power of each Class:—

Collieries	6,000 H.P.
Brick and fire clay works	1,700 ,,
Iron foundries	1,400 ,,
Woollen and other mills	1,100 ,,
Saw mills	500 ,,
Distilleries and breweries	500 ,,
Tramways	400 ,,
Chemical works	300 ,,
Other industries and small consumers	700 ,,
Total	12,600 H.P.

SOUTH WALES ELECTRICAL POWER DISTRIBUTION COMPANY.

1. Statutory Powers.—South Wales Electrical Power Distribution Company Acts, 1900, 1902, 1905, 1906, 1908.

2. Date when Supply Commenced.—March, 1904.

3. Description, Capacity, and Voltage of Generating Stations and Plant :—

Treforest Generating Station.—Three Willans engines with Ganz alternators, 1,500-k.w. capacity each. One Westinghouse turbine and alternator, 3,000-k.w. capacity. Steam pressure, 200 lbs. per square inch. Steam temperature, 550°. Surface condensers using water from River Taff. Alternators generate direct at 11,000 to 12,000 volts, 3-phase, 25 periods.

Cymbran Generating Station (now shut down owing to connecting line having been laid to Treforest).—One Willans-Westinghouse set, 750-k.w. capacity, 11,000 volts. Three Willans-Westinghouse sets, 300-k.w. capacity each, 2,200 volts transforming up to 11,000 volts. All 3-phase, 25 periods per second. No condensing plant at this station.

4. Description and Voltage of Transmission and Distributing Systems.—All the principal transmission is at 11,000 volts. Most of the lines consist of 3-core Callender cable insulated with paper, sheathed with lead, reinforced by steel wire armouring, laid in earthenware troughing, and run in solid with bitumen, covered with tiles. There are some 90 miles of cable laid in this way. There are also some 9 miles of overhead lines consisting of bare wires on insulators working at 11,000 volts.

Sub-stations for transforming down to 2,200 and to 440 volts are erected where required, and consumers are supplied mostly at one or other of these pressures.

5. Greatest Distance Transmitted.—About 25 miles.

6. Total Horse-power Connected.—8,234 H.P.

7. Nature of Industries in Company's Area. Kilowatts of each Class.—Nearly the whole of the industries in the district are collieries, and 5,509 k.w. are absorbed by them. The remainder consist of tinplate works, 324 k.w.; quarries, 87 k.w.; brickworks, 117 k.w.; and sundry small consumers of various descriptions, 153 k.w.

THE YORKSHIRE ELECTRIC POWER COMPANY.

1. **Statutory Powers.**—The Yorkshire Electric Power Act, 1901.

2. **Date when Supply Commenced.**—January, 1905.

3. **Description, Capacity, and Voltage of Generating Stations and Plant.**—Steam turbines 10,000 volts, 3-phase, 50 cycles.

4. **Description and Voltage of Transmission and Distributing Systems.**—

10,000 volts, 3-phase.
2,000 volts, 3-phase.
400 volts, 3-phase,
230 volts, single-phase.

Underground armoured lead-covered paper-insulated cables.
Overhead 10,000 volts and 2,000 volts.

5. **Greatest Distance to which Power is Delivered.**—21 miles.

6. **Total Connections.**—10,000 k.w.

7. **Nature of Industries in Company's Area.**—

Collieries and ironworks.
Textile mills.
Engineering and general.

APPENDIX III.

ELECTRICALLY DRIVEN ROLLING MILLS IN ENGLISH WORKS.

(This information has been kindly supplied by Mr. J. F. C. SNELL.)

Dorman, Long & Co., Middlesbrough (see text).

Birmingham Mint, Bronze, Copper, Brass, etc.—Two cold mills with breaking down and finishing rolls, each mill 225 H.P., 365 r.p.m., 3-phase motor.

One hot (reversing) mill and rod mill with 350 H.P., 365 r.p.m., 3-phase motor.

Birmingham Metal and Munitions Company.—Two mills for bronze, copper, and brass ; one with 260-H.P. motor ; the other with two 110-B.H.P. motors.

One mill, ditto, with 160-B.H.P. motor.

King's Norton Metal Company.

Messrs. Cooper & Foode.

Messrs. Mapplebeck, Birmingham.

Redheugh Rolling Mills, Newcastle-on-Tyne.

The Motherwell Iron and Steel Works have a 3-phase 500-H.P. rolling mill, running at a frequency of 25, coupled to a 28-ton flywheel.

The Redheugh Iron Company, Newcastle-on-Tyne, have a 700-B.H.P. 14-ton flywheel mill with a capacity of 2½ tons per hour, driving 21-in. rolls at 38 r.p.m., the material being sheets of 4 ft. to 20 ft. in length, up to a maximum of 4 ft. in width, finished from No. 9 to No. 18 B.W.G.

Summers & Co., Stalybridge.—325-H.P. rope-driven strip mill, dealing with hoop iron and strip.

W. H. Moore & Son, Birmingham.—200-H.P. geared copper and brass mill.

G. Johnson & Co., Birmingham.—250-H.P. geared brass mill, for brass and copper plates, bars and tees.

Etna Iron and Steel Company, Wishaw.—Rope-driven mill, dealing with iron and steel rods and angles.

District Iron and Steel Company, Birmingham.—275-H.P. rope-driven mill.

Pather Iron and Steel Company, Glasgow.—500-H.P. rope-driven mill.

APPENDIX IV.

ELECTRICALLY DRIVEN WINDING ENGINES

SUPPLIED OR IN COURSE OF ERECTION IN ENGLISH PITS, BY MESSRS. SIEMENS BROS., LTD.

Messrs.	Maximum B.H.P. of Winding Motor.	Depth of Shaft in Feet.	Net Load per Lift in Lbs.	Output per Hour in Tons.	Maximum Rope Speed in Feet per Second.	System.
The Priestman Collieries, Ltd.	36	250	3,500	86	8	Siemens-Ilgner.
The United Alkali Company	73	493	4,480	50	5	Siemens-Ilgner.
The United Alkali Company	33	493	2,240	20	4·16	Siemens-Ilgner.
Guest, Keen and Nettlefolds	160	95	5,040	135	7	Siemens-Ilgner.
Guest, Keen and Nettlefolds	160	95	5,040	135	7	Siemens-Ilgner.
The Cynon Colliery Company	300	600	2,800	100	25	Siemens-Ilgner.
Pease and Partners	239	309	2,016	108	19	Ward-Leonard.
Pease and Partners	78	400	1,680	45	10	Ward-Leonard.
The Duffryn Rhondda Colliery Company ...	1,420	2,000	8,960	190	50	Siemens-Ilgner.
Lambton Collieries	700	660	5,712	191	33	Ward-Leonard.
Harton Coal Company, Ltd.	1,700	1,424	9,408	207	41	3-phase.
The Denaby and Cadeby Collieries	750	780	4,480	140	32·5	3-phase.

APPENDIX V.

ELECTRICALLY DRIVEN ROLLING MILLS.

SUPPLIED BY MESSRS. SIEMENS BROS., LTD., TO ENGLISH WORKS.

Name.	Number of Motors.	Power of each Motor.	Type of Mill.
		Horse-power.	
Willans and Robinson, Queen's Ferry, Flintshire	1	275	Tube mill.
English McKenna Company, Seacombe, Birkenhead	6	500	Rail mills.
Redbrook Tinplate Company, Pontnewydd	1	125	Hot rolls.
	1	100	Cold rolls.
John Brown & Co., Sheffield ...	2	200	Bar mills.
Barker and Allen, Birmingham	1	215	Sheet nickel mill.
	1	120	Sheet nickel mill.
	1	50	Sheet nickel mill.
Henry Wiggin & Co., Birmingham	1	220	Sheet nickel mill.
	1	150	Nickel bar mill.
Crown Galvanising Company, Stourbridge	3	70	Sheet mills.
E. Lloyd & Co., Birmingham...	2	75	Nickel rolls.
Wilkes, Son, and Mapplebeck	1	150	Copper roll mills.
	1	120	Copper roll mills.
	1	75	Copper roll mills.
District Iron and Steel Company	1	250	Merchant mill.
J. and S. Tregoning	1	200	Tinplate mill.
Skinningrove Iron Company ...	1	10,000	36-in. cogging mill (reversing).
English McKenna Process Company	1	350	Variable-speed 3-phase motor.

Dr. Silvanus Thompson.

Dr. SILVANUS P. THOMPSON: I have listened to many Presidential Addresses in this theatre, but to none of them have I listened with more pleasure than to that which you, Mr. President, have been good enough to deliver to us to-night. You have had many experiences. We knew you of old in the active part you took in our debates at this Institution and in this room. Then you deserted us, and for a time you were widening your experience and enlightening the world with your knowledge from another centre, but we lost sight of you to a large extent. Happily five years ago you returned to us. We have had the benefit to-night of your ripened experience, and have admired your capacity for dealing with the information that you have gathered from all quarters, by your giving us a bird's-eye view of the progress that has been made in electrical engineering within the last few years, or even months. I am sure that the Institution will feel greatly indebted to you for the compendium that you have given us, which we shall be only too glad to digest and assimilate at home. Therefore I rise to move to you a vote of thanks, not simply because it is the custom to thank our President for his address, but because we know that you really deserve it, and that you have spent obviously a very large amount of time and pains for the Institution in compiling and putting together this address. And not only for this, but because we value you for your own sake, we are glad of this address, and we shall be glad to read it. Therefore to the motion that we give you our hearty thanks I add a clause saying that we desire your permission to have this address printed in the *Journal* of the Institution.

Dr. Glazebrook.

Dr. R. T. GLAZEBROOK: The motion which Dr. Thompson has proposed runs as follows: "That the best thanks of the Institution be accorded to Dr. Gisbert Kapp for his interesting and instructive Presidential Address, and that with his permission the address be printed in the *Journal* of the *Proceedings* of the Institution." I take it, sir, that possibly those words "interesting and instructive" are sometimes formal words ordinarily used in a resolution of this kind. Those of us who have listened to your address this evening feel, however, that they describe it in a very suitable and fitting manner. You have made this subject, with your wide knowledge, your great experience, and the obviously great labour that you have devoted to it, interesting and instructive; and although the subject is a large one, you have put it before us in a manner that will make us wish to read and study more carefully the printed address, and that will lead us to turn to the original sources that you have so wisely referred to in the footnotes to the address. In seconding the resolution, and in putting it to the meeting, may I be allowed also, sir, to wish you a prosperous and successful year of office as President of the Institution, and to hope that you may see the completion of that great work, the foundations of which have been so well and truly laid by our past President—the new home that the Institution is looking forward to. I will now ask the members to vote with acclamation the proposition that has been put before them by Professor Thompson.

The resolution was carried by acclamation.

The PRESIDENT: I thank Dr. Thompson, Dr. Glazebrook, and you, gentlemen, very heartily for the kind way in which you have received my address. The President.

The meeting adjourned at 9.45 p.m.

Proceedings of the Four Hundred and Ninety-seventh Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, November 25, 1909—Dr. GISBERT KAPP, President, in the chair.

The minutes of the Ordinary General Meeting held on November 11, 1909, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was announced as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members—

Herbert Bell. | Austin Hopkinson.

From the class of Associates to that of Members—

Allan B. Field.

From the class of Associates to that of Associate Members—

John Norman Alty.	Harry Leonard Percy.
Frank Beckett.	Arthur L. Rawlings.
C. G. M. Bennett.	John William Turner.

Joseph G. Wilson.

From the class of Students to that of Associate Members—

H. W. Bosworth.	Henry W. Kefford.
C. V. K. Chetty.	Charles M. B. Mersh.
Norman Richard Corke.	Enrico A. Pinto.
Cyril J. Hopkins.	Charles Gage Seeley.
Charles W. Jackson.	Geo. A. Tatchell.
Arthur L. Kavanagh.	Richard H. White.

From the class of Students to that of Associates—

Edgar de Lautour.

The following paper (see page 57), "The Present Aspect of Electric Lighting," by H. W. Handcock and A. H. Dykes, Members, was read and discussed.

THE PRESENT ASPECT OF ELECTRIC LIGHTING.

By H. W. HANDCOCK and A. H. DYKES, Members.

(*Paper received August* 11*th, read in London November* 25*th, and at Birmingham on December* 1, 1909.)

When we wrote our paper on "Electricity Supply and Metallic Filament Lamps," which was read before the Institution in April, 1908, the wire lamp had but recently appeared on the horizon, and there was general uncertainty as to what was likely to be its effect on the electric lighting industry.

At that time the 200-volt wire lamp was non-existent—indeed, one authority in a subsequent paper spoke of it as highly improbable, if not impossible—the smallest tungsten filament lamp obtainable for 100 volts was 25 c.p., the list price being 4s., and but few people had resorted to the expedient of putting in a transformer to reduce the voltage to 25, which was the highest voltage on which a 10-c.p. lamp could be used.

Two years have elapsed since the paper was written, and it occurs to us that it may be of interest to members to review the position to-day to see what the actual effects of the introduction of wire lamps have so far been, whether the fears expressed by some have been justified, and whether new factors are being introduced which may tend still further to modify the previous condition of affairs.

The first thing that strikes one is the extraordinary progress made by the lamp makers in the interval.

The manufacturing difficulties which led to blackening and premature failure have been almost entirely overcome, the methods of attachment and of supporting the filaments have been improved, and apart from mechanical damage, the useful life of the lamps has now been proved to be, on an average, about double that of carbon filament lamps.

It is not always easy to get exact figures as to the life of lamps under ordinary working conditions subject to the variations in voltage which occur on public supply mains, but we are fortunately able to give the figures for an installation of 653 lamps, one of the first to be fitted with transformers and 25-volt lamps.

The change was made in April, 1908, the original 100-volt carbon filament lamps being replaced by 10-c.p. 25-volt tungsten lamps. Careful note has been kept of the number of lamps renewed since then, from which it appears that, including breakages, the average life has been 1,280 hours, although they are frequently overrun.

In another case, a large building in the West End supplied from the mains of the Charing Cross Supply Company, Ltd., 105-volt lamps of 25 and 32 c.p. were substituted for the original carbon lamps. At the end of 1,083 hours of actual use, out of 980 lamps installed 70 per cent. were still burning. Lamps by various leading makers were put in, so that this may be taken as a fairly representative figure. Individual lamps under test conditions have shown far better results, but the above figures are a fairly reliable indication of what may be expected under ordinary conditions.

The price of wire lamps has also been reduced and the 100-volt 25-c.p. lamp which two years ago cost 4s. is now listed at 3s. Having regard to the longer life of the new lamps, they are thus but little more expensive than carbon lamps, a fact which cannot fail to accelerate their adoption.

Two years ago the best that a consumer on a 100-volt circuit could do was to replace an 8-c.p. 33-watt carbon lamp with a 25-c.p. wire lamp taking about the same amount of energy and costing 4s. each.

To-day he can—if he wishes—replace the 8-c.p. 33-watt carbon lamp by a 14-c.p. wire lamp, taking only half the energy and costing 2s. 9d.

So far, continuous-current stations supplying at 200 volts have not been much affected, but at least one well-known maker has now succeeded in producing a 16-c.p. 24-watt lamp for 200 volts which we are informed will be on the market very shortly at the price of 5s. We have had some of these lamps in actual use for some months past with very satisfactory results. When it is stated that the diameter of the filament is only $\frac{1}{1200}$ of an inch and its length nearly 40 in., one cannot fail to be struck by the skill of the lamp makers. Even this does not represent the limit, as we have seen in operation a 10-c.p. 200-volt lamp taking only 15 watts.

Past experience suggests that the price will before long be reduced, when there will be nothing to prevent consumers on direct-current 200-volt systems from following the example set them by those on alternating-current systems and obtaining the same candle-power as with carbon filament lamps, but with a consumption of less than one-half of the energy.

It is evident that whatever has been the effect of the wire lamp on supply stations during the last two years, it will be greatly intensified in the near future.

In our 1908 paper we ventured to suggest that the effect on those stations relying on a purely lighting load—and there are still a very large number of them—would be disastrous unless some steps were taken to alter the method of charging. We suggested that a fixed charge should be made, based on the maximum rate of supply contracted for by the consumer, which we termed his contract demand, and in addition a small charge per unit to cover the running costs.

It appeared to us that although the increased cheapness of the light, due to the new lamp, would attract new consumers, their numbers

would not be sufficient to counteract the reduced demand of the original consumers, nor would the amount they individually contributed on a flat rate basis be sufficient to cover adequately the cost of additional services and incidental standing charges.

The results of the past two years have only served to strengthen us in our belief that the flat rate system fails to meet the conditions that now obtain, and that only by the adoption of some system which secures to the undertaking a definite minimum return from each consumer based on the rate at which he contracts to take energy can purely lighting stations be profitably run. *

We are gratified to learn of the great success that has attended the introduction of the system by Mr. Seabrook into the St. Marylebone district, although possibly, as we suggested in 1908, the use of the maximum demand indicator is open to the objection that the limit may be exceeded and the contract rental thus increased without the consumer being aware of the fact until he obtains his bill.

It will probably be found better in our opinion to let the consumer fix the contract demand in advance and to give him some visible signal when he is likely to exceed it.

There is probably scarcely a single alternating-current station supplying a purely lighting load which has, within the past year, sensibly increased its output, although it may have considerably increased its lamp connections, except possibly in the case of those in competition with a direct-current station in the same area.

Experience has shown that on the average consumers have reduced their consumption even where they have somewhat increased their illumination, and the revenue received by the station per lamp connected has consequently fallen very considerably.

In one station of this kind serving a London suburb, a large proportion of the consumers were "free wired." The price of current was 5½d. per unit for this class of consumer, and a deficiency charge was made in addition of 1d. per unit for every unit by which the consumption was less than 18 units per lamp per annum.

Last year it was decided—whether rightly or wrongly—to allow such consumers to have transformers and metallic filament lamps, it being stipulated that no lamps of less than 16 c.p. would be supplied. At the same time the terms were altered to a fixed wiring charge of 2s. per annum per lamp installed and 5d. per unit for energy consumed.

It is, of course, early days to judge of the effect, but the results up to date are instructive. In the case of those consumers who have taken advantage of the new arrangement it is found that formerly their

* As Section 28 (1) of the Clauses Act provides that "the maximum power with which any consumer shall be entitled to be supplied shall be of such amount as he may require to be supplied with not exceeding what may be reasonably anticipated as the maximum consumption on his premises," it does not seem unreasonable that in place of the present statutory mimimum charge of 13s. 4d. per quarter, he should be asked to pay a rental corresponding to the maximum demand that is "reasonably anticipated."

lamps averaged 12 c.p. and their consumption per lamp installed was 15·6 units per annum.

This gave a revenue *per lamp connected* (averaging 12 c.p.) of :—

	s.	d.
15·6 units, at 5d. (as for privately wired consumers)	6	6
Meter rent		4½
Wiring rental (deficiency charge + ½d. per unit)...		10½
	7	9

Some of them have not been changed over for a complete year yet, but assuming that the uncompleted quarter of the year will bear the same ratio to the earlier part as in previous years, the results due to the change will be—

Average candle-power per lamp, 16.

	s.	d.
Average consumption, including transformer losses, 9·8 units	4	1
Meter rent	0	3
Wiring rental	2	0
	6	4

In spite, therefore, of the wiring rental being increased, in spite of an increase in the illumination of 33 per cent., the inclusive receipts per lamp have fallen from 7s. 9d. to 6s. 4d.

The reduction in consumption is obviously greater in the case of privately wired consumers on whom no restrictions can be placed as to the minimum candle-power of the lamps they use, and it may be taken as certain that in future the consumption per lamp installed amongst this class will be of the order of 6 to 7 units, whilst in many cases it will fall to as low as 3 or 4.

Even at 8d. per unit a 10-light consumer having a total consumption of 30 units per annum cannot be remunerative.

In the district from which the above instances are taken the price of gas is 2s. 6d. per 1,000 cub. ft., and efforts were made to ascertain some typical returns per gas burner installed for lighting only, exclusive of any heating or cooking.

Such figures are not very easily obtainable, but a number of gas consumers occupying *small premises* were kind enough to allow their accounts to be inspected and general particulars taken. Naturally the consumption varied considerably, depending on the habits of the household, but taking the whole of those obtained, the cost for lighting only, exclusive of cooking, but including the meter rent, averaged 12s. 2d. per burner per annum, whilst many were as high as £1.

It may be contended that it all depends on the type of burner in use. Naturally, but what we have to concern ourselves with in this case is not what the gas burner can do under test conditions, but what is the average cost per burner actually used in an average small London house.

We often speak as though every gas burner in use had a mantle. This is far from being the case, even in the better-class houses.

In the Appendix we give the results of inquiries made in a number of different localities, no attempt having been made to select the consumers.

Surely there is something wrong when, in the same district, electricity yields only 4s. 4d. per lamp and gas 12s. 2d. The reason for this, however, is easily seen.

One of these gas consumers previously used electric light: at present he has 12 incandescent gas points, and his bills are £12 4s. per annum for 98,000 cub. ft. of gas, including 8s. meter rent, or £1 0s. 4d. per burner per annum.

Assuming a consumption of 5 cub. ft. of gas per burner, this gives an average of 1,630 hours per annum per burner. Had he required the same *effective* illumination for the same number of hours with carbon lamps he would probably have used 25-c.p. lamps consuming 150 units, which at 5d. per unit would have been £3 2s. 6d. per annum. Now, however, that the 25-c.p. 30-watt wire lamp is available, his consumption would be reduced to some 50 units for 1,650 hours, costing £1 0s. 10d. per lamp per annum, to which has to be added meter rent, thus bringing the cost on the flat rate still slightly above that of gas.

A consumer of this class, however, can and should be charged on a different basis, as he would otherwise be yielding an abnormal profit to the undertaking.

It will be noted that we assume that in most cases a 25-c.p. 30-watt metallic filament lamp will satisfactorily replace an ordinary gas burner such as is normally in use. It is true that with a photometer a mantle when new will under certain conditions show possibly 60 c.p., nevertheless experience shows that with few exceptions the average man is quite satisfied with the 25-c.p. metallic filament lamp for indoor domestic purposes.

The cost of lighting is judged by the every-day user, not by the nominal candle-power of the illuminant, but by the total cost of obtaining a satisfactory effect in a room. If, for instance, a 25-c.p. lamp lights a room adequately for a given sum per annum, a consumer would not thank you for saying to him, "I cannot give you a steady 25-c.p. lamp for that sum, but for a somewhat higher figure I will give you a gas lamp fluctuating from 60 c.p. downwards."

For domestic purposes the 25-c.p. electric lamp is a satisfactory unit of illumination, and if it is more economical than the so-called 60-c.p. gas-light, the consumer will take it. Given a proper method of charging, we are of opinion that not only can this be done, but in such a way as to prove very remunerative to the electric light undertaking.

As in the case mentioned above, with the flat-rate system of charging the long-hour consumer at present uses gas. One reason for this is that owing to the loss made by the electric light undertaking on the

short-hour consumer it is necessary to keep up the price all round, and the competitive illuminant benefits.

One frequently speaks as though it were an absolute necessity to supply every consumer in an area, regardless of whether he be profitable or not. In our opinion the very short-hour consumer, from the nature of the problem, can never be a remunerative one to an electric light undertaking on the present flat rates, as the capital outlay to supply him is very nearly the same as for a long-hour consumer.

Let, therefore, such a consumer go if he will not pay his fair contribution to the cost of supplying him; let him use gas or candles, and let us concentrate our efforts on the long-hour man who gives us a greater number of working hours over which to earn interest on our capital.

At the moment it is generally the other way round, and electricity is given the unremunerative short-hour lamps *because the present tariffs make the cost of long-hour lamps too high.*

Under an equitable tariff the cost of short-hour lamps to the consumer might possibly be increased, but long-hour ones would be greatly reduced. This might perhaps result in the loss of some consumers who at present do not pay their proper contribution, but would be no detriment to the undertaking, which could then utilise the plant thus freed in supplying the great influx of long-hour gas consumers who would be attracted on the score of economy, apart from any other advantages.

In the case of the suburban station mentioned above, the standing charges per kilowatt of consumers' demand amount to £17, and the running costs 0·4d. per unit. Assuming that under a system devised to attract a different class of consumer as many as 80 per cent. of the lamps installed come on the peak (the average in the district at present is 30 per cent.), the standing charges per 30-watt lamp would be :—

		s.	d
	$\frac{£17 \times 20 \times 30}{1{,}000} \times 0·8 =$	8	2
If the lamps were used for 400 hours the running charges would be	$\frac{400 \times 30}{1{,}000} \times 0·4 =$	0	5
Total		8	7

If they were used for 2,000 hours the running charges would be—

$$\frac{2{,}000 \times 30}{1{,}000} \times 0·4 = 2\text{s.}$$

or a total of 10s. 2d. Whether the lamps be used for 400 or for 2,000 hours, therefore, only makes a difference of 1s. 7d.

The difference in cost is so little, and the business advantages, from the point of view both of the station and the consumer, of a fixed charge are so great, that we consider it preferable to make a fixed charge per lamp per annum, irrespective of the number of hours during which the lamps are used.

It obviously does not pay to go to the expense of putting in a meter, providing a staff to read it and keep it in repair, and a staff of clerks to make out the accounts, in order to check such small variations in revenue, more particularly if the relative importance of the standing charges be still further increased by the station supplying the interior wiring.

It may be objected that if there be no meter and no restrictions, the consumer will waste the commodity. If the objection were valid the present system of water supply in London would be an impossibility. It must not be forgotten further that the longer the lamps are used the greater the cost to the consumer of lamp renewals, which thus acts to a certain extent automatically as a check.

As the station is charging per lamp, it must obviously also have some check on the consumer in order that he may not, for instance, substitute a 100-c.p. lamp for the 25-c.p. lamp allowed for. We prefer to do this by using special lamp-holders such that only lamps which are sold by the station or its agents can be used. The consumer who comes back too often for lamp renewals will thus be detected and dealt with accordingly if it be found that he is wasting current.

Taking the average life of the lamps at 1,200 hours, they would use in that time, say, 36 units per 25-c.p. lamp. This at 0·4d. per unit represents 1s. 2½d., and where the station sells the lamps, the profit on their sale would to a great extent automatically compensate for the wastefulness of any of its consumers.

It is obvious, therefore, that even with a wasteful consumer the station could not lose much, and a meter can, if desired, be put in to check in special cases any consumers suspected of wilful waste. For the reasons above set forth we believe that all stations having normally low running costs could, with great advantage to themselves, supply the long-hour consumer, who at present generally uses gas, at a fixed charge per lamp per annum, which would be well below what he is at present paying. The price will naturally vary for each district, but a fair average, inclusive of wiring rental, appears to us to be 12s. per 30-watt lamp per annum for a continuous supply, and 10s. per annum for a "dusk to dawn" supply (see Appendix).

This system we call the "Contract" system, to distinguish it from the Contract Demand system.

The proposal is, of course, by no means new, but it was practically an impossible one as long as we were restricted to the carbon filament lamps. The introduction of the wire lamp and the great reduction in the running costs during the past few years have, as we endeavour to show, entirely altered the position.

Credit must be given to Mr. Wilkinson of Harrogate for being one of the first to appreciate the altered position of affairs, he having introduced into his district the principle of charging small consumers by a fixed sum of 11s. per lamp per annum.

The Contract system does more than simplify the clerical work of

the station. It is one thing to go to a prospective consumer and explain that at the price you are charging electricity is cheaper than gas. In nine cases out of ten he will be sceptical and will wait until he sees his neighbours' bills before he will come on.

It is quite another matter when you can go to him and say, "Come and look at this room lit electrically; you can have your house lit with the same lamps and can use them as you like for a fixed charge per lamp per annum."

If you can get over the difficulty of the first cost of the wiring, you have in all probability secured that man as a consumer.

A few months ago, in a suburban district where at the moment there were no electric light mains, a small house and a small shop were "free wired" at our suggestion. It was a simple form of wiring with plain fittings consisting of either ceiling lights or pendants with white opal shades.

The living rooms had a single 25-c.p. wire lamp fixed close to the ceiling, which we find gives a very pleasant light in all parts of the room. The smaller bedrooms had a 10- or 16-c.p. light.

A canvasser was sent round the neighbourhood asking the inhabitants to inspect the installation, and on calling they were informed that the Electric Light Company would wire their house free of initial expense in a similar manner to that before them, and make an inclusive charge of 10s. per lamp per annum to cover the wiring rental and the right to use the lamps as required *from dusk to dawn, and during periods of unusual darkness.*

The experiment was to test whether the offer was an attractive one; the canvasser was only employed for a short period, but he secured signed applications for some 2,000 lamps, and the neighbouring authority who were being asked to consent to a provisional order for their district, agreed to give it if the same offer of wiring and current for an inclusive charge of 10s. a light were made in their district also.

We are of opinion that in the future purely lighting stations will, in order to secure the necessary large number of new consumers, be absolutely forced, either directly or through a subsidiary company, to undertake the wiring of houses and to supply lamps—in fact, *to* sell *light*, and not electrical energy.

By this means any improvement in the efficiency of the lamp will be of benefit to the stations and not, as at present, a loss to them. It will be in their interest to do all in their power to encourage the lamp makers and to seek to give the maximum illumination for the minimum of current.

At present, what do we see? Half the electrical world counting their losses due to an invention which should have proved, and may yet prove, as great a benefit to the industry as it undoubtedly is to the consumer.

To bring this about, however, other innovations must follow the introduction of the wire lamp. Among others, it is all-important that the cost of wiring should be reduced, and as many of the new con-

sumers will have only a few lights, that the cost of services be brought down also.

During the past year or so considerable attention has been given to this problem, and a number of very excellent systems of economical wiring have been launched on the electrical world. They all have their good points, and it is for each engineer to select the one which best meets his requirements.

On alternate-current systems some form of concentric wiring with earthed outer is not only the cheapest, *per se*, but enables considerable economies to be effected in other directions. Only single pole switches and fuses are required, and the insulation of the one pole can be abolished or reduced to a very small amount. Since the advent of the wire lamp a large number of concentric wiring installations with earthed outer have been put in, using a double-wound transformer, so that the supply mains are absolutely distinct and separate from the interior wiring.

Some might object that, as lamps of 25 c.p. are now available for 200 volts, the use of a transformer is unnecessary. It must not be forgotten, however, that even if nothing less than a 25-c.p. lamp is required, the price of the 200-volt lamp is 4s. 3d., and of the 50-volt, 2s. 9d., or 16-c.p., 2s. 6d., to say nothing of the greater durability of the lower voltage lamp. The cost of a double-wound transformer is now so low that the saving on the first cost of the lamps is sufficient in most cases to cover it, whilst the saving in renewal of lamps, coupled with the efficiency of the lower voltage lamps, amply suffices to meet the cost of the magnetisation units. Hence the difference in cost of wiring due to the use of one wire instead of two is pure gain.

The great majority of small consumers, the men who burn their lamps long hours and pay the gas company anything from 12s. to £1 per lamp per annum, live in terrace houses. There is nothing to prevent a whole terrace of houses from being wired from a single transformer fixed on the outside wall of the building, thus making one service supply a large number of houses, a tapping from the high-tension main being run up the front or back of one house of the terrace to a transformer fixed in a cast-iron case just below the first-floor windows.

The transformer reduces the pressure to 50 or 100 volts on either side of a 3-wire circuit, the neutral of which is earthed. From the transformer the concentric wires can be neatly cleated to the outer wall just below the window line and looped into each house in turn.

As only a single cable is needed, which is cleated direct on to the wall and neatly painted, permission can in most cases be readily obtained from owners of property for it to be run from house to house, so that one service does for a whole terrace or colliery row.

In this way it is possible in many districts to make the service charges per kilowatt of consumers' demand no more for this class of long-hour consumer with few lamps than for existing consumers, more

particularly as the cost of the meters is saved. The wiring can, by adopting one or other of the new systems, be brought down to 10s. to 12s. per light, or, say, 1s. 3d. per annum for upkeep, interest, and sinking fund.

We have seen above that even where the standing charges amount to £17 per kilowatt of consumers' maximum demand, a figure which is not likely to be exceeded by many stations, and allowing for 80 per cent. of the lights installed being on at once, a 30-watt lamp can be supplied for from 8s. 7d. to 10s. 2d., or, including the free wiring, for 9s. 10d. to 11s. 5d. per annum. It is not likely that the average burning hours will be as high as 2,000, so that it is evident that an ordinary long-hour consumer can be supplied under these conditions for a sum not exceeding 10s. to 12s. per 30-watt lamp. As it is not proposed to put 30-watt lamps in the smaller rooms, a 10s. inclusive charge would in many cases be amply justified.

In suburban and country districts, for which the foregoing system is particularly suited, there is generally very little demand for current during the daytime. At any rate, for the present one may very well leave methylated spirit or gas to heat up an occasional afternoon tea-kettle or to light a cellar lamp.

Particularly with a small alternating-current station, great economies can be effected if a supply be only given from dusk to dawn, the station being shut down during the daytime, and provisions are made under the Board of Trade Regulations whereby consent to this may be obtained.

In addition to the saving in labour at the station, the limited hour supply reduces transformer losses, and also prevents any waste of current during the daytime.

By using internal combustion engines current can be quickly turned on in the case of fog or unusual darkness, under which conditions a supply is given.

In three districts for which Provisional Orders have been recently obtained, it is proposed to work on this plan, and the necessary consents have in each case been given by the local authority on pointing out that, for the sake of one or two who wished to burn an odd light in the daytime, it would be necessary, if a continuous supply were insisted on, to increase the price to the great majority who only require light during the hours of darkness.

Of course, there is not quite so much gain from this source if the station be run with steam plant as if gas or oil engines be used.

Whilst in most districts it will pay a man with only a few lights, which he uses in consequence for fairly long hours, to use electricity at the above price per 30-watt 25-c.p. lamp per annum to cover wiring charges and the use of current as required, the man with fifty lamps would find the charge too high. Nor, indeed, would it be justified, as we have assumed so far that 80 per cent. of the lights installed are turned on at once, whilst the consumer with a greater number of lamps will probably never use at one time more than a small proportion of his

lights, the great majority of which will only be in use for a comparatively short time per annum.

To meet this difficulty, we put in a limit indicator, ask the consumer to switch on the maximum number of lamps he wishes to use at once, and charge him, say, 12s. per 30-watt lamp, calculated on the number to which the limit indicator is set, and 2s. per lamp on the remainder to cover the wiring charges. He thus settles his own diversity factor and is charged accordingly.

This enables him to put in lamps where he naturally would not use them if he had to pay full price on all lamps, and at the same time obviates the absurdity one so often sees, viz., a station providing capital for free-wired lamps which do not even pay the annual wiring charges.

Another plan which has been adopted is to charge, say, 10s. per lamp for the first five lamps, 8s. per lamp per annum for the next five, 7s. 6d. per lamp per annum for the next ten, and 5s. per lamp for all above that number, the exact figures depending on the size of the average installation in the district.

Such a scale is, in most cases, however, not so satisfactory as the first plan, as it assumes that the habits of all consumers having an equal number of lights installed are the same, which is generally far from being the case.

We venture to think that the future of electric lighting lies more especially amongst those consumers whom gas has hitherto claimed entirely as its own.

No gas company can afford to lay on gas, make a fixed charge per annum dependent on the number of burners, and allow the consumer to use as much gas as he pleases. We believe that an electric light company can deal with the consumer on this basis and make a profit out of it.

Comparing the present proposals with the conditions obtaining only three years ago, what do we find? The standing charges of the station and mains per unit of candle-power capacity have, by means of the wire lamp, been reduced by nearly two-thirds; by using double-wound transformers interior wiring becomes single wire instead of double; a main cable consisting of a single No. 18 wire can, at 100 volts, supply all installations of twenty 16-c.p. lamps or under; the old double-pole distribution fuseboard is replaced by a single 5-ampere fuse; the meter becomes a memory of the past; a single service supplies a terrace of houses, and electric light commends itself to all long-hour consumers on the score of price independently of other considerations.

Probably in a very few years supply mains will be extended into most districts which till now have been neglected because they only contain small houses. The generating stations will use internal combustion engines, which, in many cases, will only work during the hours of darkness, the supply being alternating-current single-phase at about 2,000 volts. Scattered houses will be supplied from trans-

formers fed by tappings direct off the 2,000-volt mains, and the more thickly populated districts off the low-tension networks. The interior wiring will be put in by the supply company or their agents, and will be "earthed return." The lighting of the living-rooms will be by means of single 25-c.p. lamps with plain white opal or similar shades fixed direct on the ceiling, thus giving a well diffused light and avoiding risk of mechanical damage to the lamps.

Book-keeping and collection duties will be reduced to a minimum, as there will be a fixed inclusive charge of about 2s. 6d. to 3s. per lamp per quarter, paid in advance, and the first quarter's charge might with advantage be made to become due as soon as the house is wired.

We give in Appendix B estimates for a 10,000-light station working on these lines.

On this basis, capital will find in electric lighting as safe an investment as it does in water or other high-class securities, and as soon as this is realised, not only the investor, but every one connected with electricity, will reap the benefit.

APPENDIX A.

TYPICAL GAS CONSUMERS' ACCOUNTS.

1. *Private House at Shortlands.*

Gas in servants' quarters; electric light elsewhere.

Annual gas bill, 49s. 4d. for five incandescent gas burners = 9s. 10d. per burner.

House is shut up for some weeks in summer and also at Christmas, so that an ordinary year's consumption is greater.

2. *Small House at Shortlands.*

Ordinary meter. Gas, 3s. 2d. per 1,000 cub. ft.

1 point in kitchen.
1 point in scullery.
1 point in passage.
3 points in bedrooms (very little used).
1 point in living-room.

—
7

In the ordinary way three burners are going at once, and the consumption for various quarters varies from 13s. to 15s., or, say, 56s. per annum—that is 8s. per burner.

3. *Small Shop in Camberwell.*

3 burners.
1 ring burner, used occasionally for boiling kettle.
Total consumption, 42,400 cub. ft. of gas per annum.
Gas, 2s. 6d. per 1,000 cub. ft.
Total gas bill, £5 6s. per annum.

4. *Small Shop in Shortlands.*

Slot meter.

Occupier stated that 1d. would run his incandescent burner from 3 to 3½ hours as a maximum, and an ordinary burner which he had, 2½ hours as a maximum.

In winter he put in the meter about 3d. per night.

5. *Dwelling-house in Southwark.*

Total, 6 lights installed.

It was stated that these were used until about twelve o'clock at night.

Bills average just over £10 per annum.

No cooking.

6. *Small House at Bromley, Kent.*

Slot meter.

Occupier has 1 incandescent gas burner in living-room.

" 1 ordinary burner upstairs.

Gas is not always used on account of expense.

When it is used it takes 3d. for a winter's evening to keep the light going downstairs, the light upstairs being merely turned on for a few minutes when going to bed.

At other times they use oil lamps, the consumption being one quart of oil per week.

7. *Small Office, Chelsea.*

Ordinary meter.

Two lights installed in September, 1908.

Total gas bill for 3 quarters ending June, 1909, 18s. 3d.

8. *Shop and Living-room, South Kensington.*

Installed—2 incandescent burners.

2 ordinary burners (one seldom used).

1 gas ring (used occasionally).

Price of gas, 2s. 10d. per 1,000 cub. ft.

Total gas bill for one year, including meter rent of 5d. per quarter, 46s. 6d.

9. *Shop, Bermondsey.*

27 incandescents in shop.

3 in house.

2 flat flame burners.

1 gas stove.

Maintenance, 9d. per burner per quarter—3s. per quarter meter rental.

	£	s.	d.
Total gas bill	31	13	9
Maintenance	4	1	0
	35	14	9

10. *Shop and Parlour, South Kensington.*
Installed, 6 incandescent gas burners; no stoves.
Ordinary meter.
Average accounts, £4 per annum.

11. *Small House, Chelsea.*
Installed, 2 incandescent gas burners.
Slot meter.
Cost of gas averages 3d. per day, or, say, 1s. 6d. per week in summer, and about 2s. per week in winter.

12. *House at Chelsea.*
Let off in flats of two rooms.
Separate meter for each flat.
One incandescent burner fitted to each flat.
Average cost to each consumer is 2d. per day, or, say, 1s. to 1s. 6d. per week.

13. *Shop and Parlour in Chelsea.*
Installed, 3 incandescent burners.
Slot meter.
Average cost about 2s. weekly in summer, and 2s. 6d. in winter, or, say, £5 17s. per annum for three lights.

14. *Small House in Chelsea.*
Installed—1 incandescent gas burner.
6 ordinary burners.
1 gas burner.
Average cost throughout the year is from 4d. to 6d. per day.
Slot meter.

Occupier states that he is supposed to get 25 cub. ft. of gas for 1d., which with only one burner in use will last about 3 hours.

15. *Large Block of Tenements.*
Let out in flats of 3 rooms and scullery.
Installed—2 incandescent gas burners in each flat.
1 gas ring.

From a number of inquiries the average cost of gas in each flat appears to be about 2d. per day in summer, and from 3d. to 4d. in winter.

16. *House at Shortlands.*
Installed—4 incandescent gas burners.
1 small gas iron.

	£	s.	d.	
Total gas bill	2	10	0	
Meter rent	0	3	0	
Repairs and renewals ...	0	4	0	
	2	17	0	per annum.

17. *Shop at Shortlands.*

Installed—13 incandescent gas burners
1 small gas ring.

	£	s.	d.
Total gas bill	11	4	6
Meter rent	0	3	0
Repairs and renewals ...	0	14	0
	12	1	6 per annum.

18. *Small Shop and House Combined, Shortlands.*

Total installed, 12 lights.

	£	s.	d.
Total gas bill	12	4	0
Meter rent	0	6	0
Repairs and renewals ...	0	5	0
	12	15	0 per annum.

19. *South London—Shop.*

Installed—8 flat-flame burners (6 only used).
2 incandescent burners in house.

Total gas bill for 12 months, £5 8s. 4d.

20. *South London—Shop.*

Installed, 8 incandescent gas burners (2 in house).

Total gas bill for 12 months, £10.

APPENDIX B.

CAPITAL COST OF STATION, MAINS, AND CONSUMERS' WIRING, FOR A TOTAL OF 10,000 LIGHTS CONNECTED.*

	£
Site	400
Buildings, foundations, and overhead crane ...	1,000
Three 100-k.w. gas alternator sets, and suction gas producers	5,200
Switchboard, connections, and accessories ...	500
12 miles high-tension, 0·05 sq. in. concentric mains laid complete, at £500 per mile	6,000
Services and transformers (assuming that each service supplies more than one house) ...	3,000
Wiring for 10,000 lights at 10s.	5,000
	21,100
Contingencies, 10 per cent.	2,110
Total	£23,210

* The mileage of mains and cost of services obviously depends entirely on the characteristics of the district.

WORKING EXPENSES OF STATION.

RUNNING FROM DUSK TO DAWN ONLY WITH 10,000 LIGHTS CONNECTED AND GENERATING 300,000 UNITS PER ANNUM.

Receipts.		£
10,000 lights at 10s. per annum, including wiring rental		5,000
Expenditure.	£	
Coal, oil, and waste	500	
Wages and salaries	584	
Repairs and maintenance	200	
Rates, taxes, insurance, office, and collection expenses	612	
	1,896	
Add 3 per cent. for sinking fund	696	2,592
Net result on outlay of £23,210		£2,408

APPENDIX C.

COMPARISON OF FIGURES OF AN EXISTING UNDERTAKING WITH WHAT THEY WOULD BE IF IT WERE SUPPLYING AT 12S. PER 30-WATT LAMP PER ANNUM WITHOUT METERS, ASSUMING THAT THE SAME MACHINERY AND MAINS WERE USED, AND THE SAME TOTAL SUM SPENT ON SERVICES.

Present Figures.

Flat rate approximately 5d. per unit, 54,000 30-watt (equivalent) lamps connected; maximum load, 560 k.w.; units sold, 600,000. Expenditure on services and meters, £7,800 = 2·9 shillings per 30-watt lamp. 23,000 lamps are "free wired" at present at an average cost of just over £1.

Gross revenue, including meter rents and wiring rentals, £13,000. Running costs, 0·44d. per unit.

On Contract System at 12s. *per Lamp.*

Assume that owing to being all small long-hour consumers as many as 80 per cent. of all lamps connected came on the peak, and that the lamps are run on an average as much as 1,500 hours per annum. The capacity of the station thus becomes:—

$$\frac{560 \times 100}{80} \times \frac{1}{30} = 23{,}300 \text{ 30-watt 25-c.p. wire lamps.}$$

Revenue at 12s. per lamp per annum £13,980.

As no more lamps have to be wired than before the only additional cost is that of producing, with the same maximum load, the additional units, the output now being—

$$\frac{23{,}300 \times 1{,}500 \times 30}{1{,}000} = 1{,}048{,}000 \text{ units},$$

an increase of 448,000 units which at 0·44d. equals £821. This gives a net increased profit of £159 plus the saving by the abolition of the meter department.

The sum available for services per lamp connected is now—

$$\frac{£7{,}800}{23{,}300} = 6{\cdot}7 \text{ shillings},$$

leaving out of account the saving to be effected owing to the reduced cost of house wiring.

Discussion.

Mr. Wilkinson.

Mr. G. Wilkinson: The paper is full of points of interest which invite discussion, but I propose to confine myself to some of the points appearing in the earlier part. In reading it over I was struck with the idea that the authors have written this paper chiefly from the point of view of profit making, or, shall I say, from the company point of view, rather than from the municipal point of view; but I think there are ambitions other than making profit which should animate a municipal engineer. He ought to endeavour to reduce his production costs, and to arrange his tariffs so that not only is he able at the end of the financial year to show a little surplus, but also to bring the advantages, comforts, and healthfulness derived from electrical illumination within reach of the poorer ratepayers of the town as well as of the more wealthy. On page 58 the authors state they fear that whatever effect has already taken place "will be greatly intensified in the near future." I admit that in many cases this is true, but in the case of such towns as Tunbridge Wells, Cheltenham, Bath, and Harrogate, where the undertakings are entirely dependent for success upon the supply of electricity for illuminating purposes, we have already felt, and felt to a considerable extent, the effect of the introduction of the metallic lamp. I know most about Harrogate, and so far as that town is concerned, as near as we can ascertain from the various wiring contractors and lamp manufacturers, something like half the total number of lamps are metal lamps. We have for private lighting the equivalent of approximately 80,000 30-watt lamps, the population of the town being 32,000. Probably this is as good an average per head of population as, if not better than that of any other town in Great Britain. We have, with few exceptions, all the hotels, hydros, and public buildings as customers, together with a good proportion of the better-class residences, and most of the business premises, so that really the cream of the business, so far as Harrogate is concerned, has already been obtained, and now we have to look to the "skim milk" for anything further. I have been

Mr. Wilkinson.

looking up the effect of the metal lamps on the units generated during the last seven months—that is, from the commencement of our present financial year—and I find we are only 2 per cent. down in our units generated compared with the previous year. During this last month (October) we added to our mains a total of 622 new lamps. I think that may be looked upon as showing a healthy growth of business, and I do not take a despairing view of the future of the supply of electricity, even in areas which are dependent upon illumination alone for their revenue, provided such undertakings are well managed. With regard to tariffs, the authors state on page 59 that the flat rates are practically doomed, and I thoroughly agree with that, because the loss of revenue from our old customers cannot be made up, if we have flat rates, by the increment of lighting business from other sources. The demand indicator tariff, again, is too complicated for the average lay mind to grasp, and it is very expensive in its application. You cannot afford to put such a system into houses and buildings where the demand for current is very small indeed. In their 1908 paper the authors suggested the following tariff—viz., that a fixed charge should be made, based on the consumer's "contract demand," and, in addition, a small charge per unit to cover running costs. This system required the units consumed to be measured by an electric meter. Apparently they have thought further of the matter, and followed the same line of reasoning that I did in considering the question, and reached the same conclusion—in order to make a reasonable profit on small houses it is imperative to have a fixed price per lamp. This is set out on page 63, where it is designated the "contract" system. It is the system which we introduced into Harrogate some considerable time ago, and this was not done without very carefully going into figures. We found that, taking a large number of typical cases, the demand-indicator customers were paying us 7s. 7d. or 7s. 8d. per annum per 30-watt lamp, so that we decided to have a fixed price of 2s. 9d. per quarter, or 11s. per annum per 30-watt lamp. That, as you will at once realise, gives a substantial margin on the average price obtained on the demand system, and also upon the flat rate, the average price obtained from which was slightly less than that realised from the demand-indicator customers. The basis upon which our contract rate is founded is that if a customer uses every light that he contracts for for eight hours a day the undertaking will not lose any money—that is, he can have all the lamps contracted for alight for one-third of the total number of hours in the twelve months without incurring loss upon the supply department. This has proved to be a sound policy, and it is also proved on page 62 of the paper, where the authors take a typical case and show that the standing charges amount to 8s. 2d. per lamp on the particular station—I do not know where it is—and the charges for running for 400 hours are only 5d., bringing up the total to 8s. 7d. for the year. Our figures are somewhat better than these, as we have not such heavy standing charges. If you will look lower down on the same page you will find that if the consumer uses his lights 2,000 hours

a year he only increases his running charges on the station from 5d. to 2s. If you add that on to the 8s. 2d. it is only 10s. 2d., so that there is ample margin for profit on our contract rate per lamp per annum. I have brought with me a form of agreement which the Harrogate Corporation enters into with the consumer. First of all, he pays in advance. That is necessary in the case of small houses let to weekly tenants at a rent of, say, 6s. 6d. or 7s. 6d. per week, and prevents absconding tenants from defrauding the undertaking of their dues. The conditions, which are very simple, are three in number, and are as follows: (1) The tenant undertakes that he "will only use the said electrical energy in the evening-times and during such periods of the day when ordinary occupations cannot be carried on owing to dull weather or storm, and will not at any time use it in a wasteful manner; (2) the said tenant will use the said electrical energy for lighting purposes only; (3) the apartments in which the said lamps are fixed shall in every instance be satisfactorily illuminated by daylight during daylight hours, so that no artificial light is necessary during such hours." I think those conditions will bear examination and can easily be understood, and the price fixed is one that permits of the supply authority making a profit. It is also a tariff that gives satisfaction to the users, because they know exactly what they have to pay. In some cases consumers have come and said, "We wish to give up our meter, although this contract system is rather more expensive, because we know exactly what we have to pay," and we have actually removed meters and put consumers on this contract system. I had great difficulty in finding a current limiter which would deal with the small current used by metal lamps. I may say that the contract is entered into for a minimum of two lamps and a maximum of six lamps. A man may have, say, twenty lights installed in his house—he has perfect liberty in that respect—but he cannot use more than the number he contracts to use. The current limiter is set so that he cannot possibly draw from the mains any more current than the contract demand allows. If he does it sets up a vigorous blinking, which makes his eyes ache, and compels him to reduce his demand. There is another point that greatly pleases the small householder, and that is that he is able to go out in the evening and leave a light in the front passage. When gas is installed in a small house you will find with few exceptions that when people go out in the evening they leave their house in the dark, but under this system it is possible for them to go out and leave the light burning in the front passage without increasing their lighting bill. With regard to the question of wiring mentioned on pages 64 and 65, the writers advocate a particular system of wiring. We are able to get the houses wired from 8s. 6d. to 9s. per point, and the tenant himself has to pay 5s. 6d. per point for his pendant, shade, and lamp. The question of the services is a very important one, because they were costing us on an average £7 per service. We have succeeded in getting that down to 35s. to 40s., and the whole arrangement does not cost more than 50s. to 55s. including the cost of the limiter. We do

Mr. Wilkinson.

Mr. Wilkinson.

not allow in these services any margin for heating and cooking. I submit it is a waste of money to lay heavy cables and services in a neighbourhood such as I am referring to, because both the first cost and also the running cost of cooking and heating apparatus is too heavy, and in the poorer districts we cannot hope to displace the gas stove for such purposes. Then, again, we have to pay off the loans in fifteen years, and heavy repayments of capital would leave no margin for profit if we put in expensive services and meters. I should like to say that the limiters, of which a sample has been brought to the meeting, are calibrated, so that the atmospheric temperature does not affect them. They are compensated so as to neutralise any effect of that kind.

Mr. Pierce.

Mr. R. C. PIERCE: The chief point I wish to raise is that I find it very difficult to keep down the cost of wiring. It seems to me that the cost of wiring, at any rate in Cambridge, is the great thing standing in the way of people coming on to our mains. We find that it is almost impossible to keep down the cost wiring below £1 a point, or thereabouts. The £1 a point includes a metal filament lamp, a plain pendant complete with a 1s. shade and the necessary transformer. Another thing we find is this: If you take an ordinary house with anything like twenty lights in it, the total revenue that we get per lamp is 3s. to 3s. 6d., so that it rather seems that with the system of rental that is indicated, in the case of large consumer whose houses are wired throughout, you might materially reduce the charge to the consumer per lamp below what is stated and still make a profit—because I may say that we manage to make a profit. There is no doubt from the station engineer's point of view that the metallic filament lamp brings on a great many consumers. For instance, this year we have put on 170 consumers, including three colleges, each of which is equal to about 30 or 40 small consumers. We have put on 6,000 30-watt lamps, and the whole of that increase is entirely due to the cheapening of the cost of electric light. If you tell a man that he can burn a 20-watt lamp giving 16 candles for 0·12d., or rather less than half a farthing an hour, he is impressed by the fact, and although the metal filament lamp has naturally taken away our revenue, I think it will help us in the end, and if we can adopt some system of rental as that suggested by the authors, I think we shall be all right.

Mr. Cooper.

Mr. W. R. COOPER: I consider that the question of tariffs is of the greatest importance, the future success of electricity supply being to a large extent bound up with the selection of a suitable tariff. The system advocated, as the authors mention, is not novel. It has been in use for a long time on the Continent, and since Edison screw sockets are there common the bayonet joint can be used as an alternative where it is desirable to control the supply of lamps. The converse course might be followed in this country. Apparently, the authors think of running a whole undertaking on the "contract system." I doubt if that would be good policy, because small undertakings gradually become larger undertakings and the conditions change.

If all consumers were precisely alike in their demands there would be very little difficulty, but this is not so. A contract system is good where a man has but few lamps and requires them for long hours. But in the case of a consumer having a number of lamps, many of which are used but seldom, the contract system becomes prohibitive. Moreover, one cannot help feeling that if the contract price is fixed for the long-hour consumer, as it must be, then it is unfair to the shorter hour consumer. Of course, one may take the view that the short-hour consumer is undesirable, but this is only the case if he does not pay his proper share of the fixed charges, and there is no good reason why he should be penalised. Mr. Cooper.

I feel that the authors' conclusions are much too sweeping. If the only object were to sell electric energy for light, these conclusions might be endorsed, but most supply engineers hope for something better. For that reason, I think the suggestion of using so low a pressure as 25 volts for distribution generally is a serious mistake, though quite desirable in special cases of blocks of houses or tenements of the poorest class. By adopting such a course the possibility of cultivating a load from heating or cooking or any other domestic applications is at once eliminated. Supply engineers complain of the very bad load factor of lighting loads, but at the same time it seems to me they will, if they adopt the principle advocated by the authors, cut themselves off from the only possible remedy. The electric flat iron, for instance, is a very useful little device, the use of which may be encouraged with very good effect under certain conditions; but if the pressure is only 25 volts this becomes impossible. It is also necessary to remember that the metal filament lamp is still young. Prices will certainly fall considerably, so that the first cost will become less important, compared with the cost of energy, than at present. I should like to ask the authors, therefore, whether it is not worth while to consider the possible alternative of running 100-volt overhead circuits in small towns. On the Continent overhead wires are quite common. In this country, for some reason or other, they are looked upon as dangerous.

Another point to which I should like to refer is the way in which metal filament lamps are being used at the present time. It seems to be increasingly the custom to use such lamps with clear globes. It is quite a common thing to see the lamps so placed that it is impossible to look about the room or office in which they are fixed without the filaments appearing in the field of view. I cannot help thinking that this is a serious mistake. Apparently engineers do not realise how extremely high is the intrinsic brilliancy of the metal filament. Stockhausen has given the following figures of brilliancy :—

Incandescent gas mantle ...	35	c.p. per square inch.	
Carbon filament of glow lamp	540	,,	,,
Metal filament of glow lamp...	1,100	,,	,,

Professor W. E. Barrows gives figures that are somewhat lower,

Mr. Cooper. and mentions that the intrinsic brilliancy of a gas flame is 3 to 8, and that of a frosted glow lamp is only 2 to 5. It seems to be generally forgotten that the effect of a brilliant source of light in the field of view is to diminish the sensitiveness of the eye (to an extent of some 30 per cent., according to Professor Ashe), and thus to render the illumination much less effective. Therefore illumination in such a way is simply waste of light. It is useless to provide good illumination, as measured by the photometer, if the eye is rendered insensitive thereby, for, after all, the eye is the final judge of the effect, and therefore the physiological aspect of the question must not be disregarded. A still more important point, however, is the harm that may be done to the eyesight by such brilliant sources of light. That harm can be done to the eyes by excessive brilliancy is well known, and I am very much afraid that if present methods are continued, injury may be done to the general public, who are ignorant of these matters and are quite content to look habitually at incandescent metal filaments because we engineers place them in their field of view. If this comes about there is no question that electric lighting will get a bad name from which it will not easily recover. It appears that the only compensating advantage is the saving of 5 per cent. or so in the cost of clear globes over the frosted or semi-frosted type, and this certainly is not worth considering. I would, therefore, urge members of this Institution most strongly to put down the present injurious practice before any harm is done.

Mr. Wordingham. Mr. C. H. Wordingham: I am bound to say that personally I should feel an apology necessary at this time of day for reading a paper on methods of charging, which to many of us is a well-worn subject. I have read countless remarks on methods of charging, but I have never read a single syllable that added anything to Dr. John Hopkinson's classical paper read in 1893. In that paper the whole principle is laid down, and to my mind he showed conclusively that the only correct method of charging was a sliding scale. Like most of his work, that work was done for all time, and I do not think it is any disgrace to further writers to say there is nothing to add to it—the whole principle is laid down there. The authors in this paper are merely rubbing in a fact which nobody can get over. Without a sliding scale it will never be possible to compete with gas. It is ludicrous to charge the long-hour consumer at the same rate as the short-hour consumer. If that is done, the gas companies will go on for ever, and electric lighting will never get their business away from them. In some towns there is an immense amount of basement lighting, and electric lighting undertakings cannot hope to get that without charging a sliding scale. Therefore I think this paper is simply reiterating, so far as it relates to the sliding scale, what has been said before, and what to many of us is simply an axiom. With regard to the remedy proposed by the authors for the troubles they mention—namely, charging a contract rate—I am bound to say that I entirely disagree with them. I think it is altogether unsound with central stations run as they necessarily are run in this

Mr. Wordingham.

country. I cannot think it is right to charge a price per lamp whatever the number of hours that lamp is used. I have a very vivid recollection of the introduction of meters by the London Electric Supply Corporation. When they started they charged a contract rate, but as soon as meters became available they installed them. It fell upon me to see a good many consumers to explain that the meters which I had tested were right. It was manifest that many of the consumers under the old contract rate had been paying three times what they paid when the meter was introduced. Those gentlemen were not the consumers who thought their meters were not quite right. But others had not been paying one-third under the contract rate of what they had to pay when charged by meter, and they did complain very strongly. I must say I was very much struck by the touching document read by Mr. Wilkinson. That document shows an unlimited faith in human nature. I remember quite well going to a large art dealer—I will not say in what street—but his name is very well known. He had furiously disputed his meter, and spoke very unkindly of the company, and of myself in particular. He explained to me, when I went to see him, that he never had his lamps going in the daytime, and that it was quite impossible he could have consumed the amount of current that we said he had consumed. After hearing what he had to say I went away, but I had the curiosity five minutes later to walk past his premises again on the opposite side of the street, and I found that although it was broad daylight, the building was lighted up from top to bottom, although he told me when I was talking to him that he never had a lamp alight in the daytime. I reported this, and he got a letter from us that he did not like. But I did not dare go down that street again; he was simply thirsting for my blood, because he knew I had found him out. There are one or two points in this paper to which I should like to call your attention. On page 63 the authors have given a splendid idea for "doing" the consumer, and that is to supply the lamps to him, and so arrange the holders that he can only use the lamps which the company supplies—of course at a good profit to the company. That is absolutely illegal; it is expressly forbidden in the Act of Parliament, which says that no undertaker shall prescribe any particular burner, so I am afraid that little scheme goes by the board. With regard to the use of metallic filament lamps, every little piece of personal experience at this present juncture is worth mentioning. I had occasion to wire my own house last July twelvemonths, and I put in metallic filament lamps, 25 volts. Many of the lamps burn rather long hours, but I may say that the first lamp to burn out did so last week, and that was the lamp in the hall, which really does get very long hours of burning. I think that is a very good result. With regard to the question of low-pressure lamps, I quite agree that at the present time it pays well to put in a transformer and low pressures. There is only one other point I should like to refer to, and that is the proposal to run stations for only a part of the twenty-four hours. I feel strongly that this is a most mistaken policy. To cite my own case again, if this were done by the Corporation, they would

Mr. Wordingham.

cut their revenue from us down to about one-fifth or one-sixth of what it is at present, because we are using radiators rather extensively. Those must go if that takes place, because we want them in the day-time—you cannot afford to shiver during the day in order to please the supply authority. Speaking as a former central station engineer, I do feel, and always have felt, that the primary thing for a central station engineer to aim at is continuity of supply. If the consumers cannot look upon electric supply in the same light that they do water or gas, they will have none of it. They must have it always on tap whenever they want it.

Mr. Seabrook.

Mr. A. H. Seabrook: It is perfectly true that the contract demand system is based on the Hopkinson rule—of course, further improved by Arthur Wright some years afterwards. But, unfortunately, so many of us have fallen from grace. We have not been content for five or seven years with adhering to that accepted correct theory of charging, and many of us have gone back to flat rates. I do not claim to be any better than anybody else. I was responsible for scrapping a demand system some years ago which I should be very sorry to do to-day. But at the same time, although it is a well-worn subject, I do think it necessary that the question of tariff reform should be considered very carefully by members of this Institution. There are one or two points which I do not quite agree with in the paper, and, first of all, I wish to refer to the questions of no meters, and dusk-to-dawn supply. I have had no personal experience of either of those systems, but, judging by American practice, it seems that most of the central stations which adopted those systems there have gone back to measured and continual supply. From my own point of view I am perfectly convinced that the authors are correct in their recommendation of the contract demand system. I think we must have a small running charge per unit to prevent waste. With regard to the flat rate, I cannot now think of any good word to say for it. From three points of view that has been proved very distinctly in my district. Firstly, for shop-window lighting, no flat rate will induce shopkeepers to light their windows until midnight and get that form of advertisement. A flat rate is too expensive; but at a small fixed charge, plus a penny a unit, it is quite possible to do that with advantage to themselves. There are hundreds of consumers in every district who are wired for electricity and piped for gas, and what happens in such cases? The gas is burnt all day for the long-hour work, and at night when the electric light people do not want it electricity goes on; whereas, by a contract demand system, with an annual charge and a small charge per unit, it would not pay those consumers to use gas because it could not compete with electricity at a penny a unit. Again, in basements the gas is burning away all day, and the electricity in the rest of the house is not used at all. The flat rate does not encourage the long-hour consumer. I contend that the flat rate does not charge the consumers fairly, because they do not pay their proper proportion of the standing charges. However we may alter

our tariffs it does not alter the fact that if a man has changed his lighting from carbon lamps to metal lamps he will not pay as much revenue to the company as he did before. I think the authors have only gone half-way. The revision of tariff and the going back from the flat rate to the demand system is a good half-way on the journey, but we have to do something to make up for the unremunerative mains and services, which will be more intensely noticed in the future on account of the decrease of revenue owing to the use of metal lamps. It is not any good to try and remedy this by developing a big power load in another part of the district; you still have that capital used, the charges on which have to be paid. I believe there is a great future for the auxiliary uses of electricity. I was very much struck the other day in speaking to the manager of one of the large London companies when he made a very remarkable, but perfectly true, statement to the effect that the old-fashioned link between the supply undertaking and the consumer by way of the accountant, the meter reader, and a few underpaid touts is nothing like sufficient to bring about the interest of consumers in the undertaking. When those responsible for the management of the undertaking show consumers that they take an interest in them, and are anxious to introduce new, improved, and efficient apparatus to their notice, this manager told me that he has found from experience that in quite a short time he cannot keep his showroom stocked, because directly he gets a few things in they go out before he can get another supply. He told me his greatest trouble is that he cannot get the apparatus for cooking and heating fast enough from the manufacturers. This really augurs well for the future of the accessory uses of electricity, if it is properly introduced to the notice of the consumer. In my own case we have adopted this policy for only a few weeks, and it will be surprising, I think, to most people to hear that now the orders from consumers have reached £250 a week. Only a small portion of that is for wiring; it is mainly for accessory uses—alterations for the efficient arrangements of lamps, lighting, fans, radiators, cookers, grillers, and so on. When it is remembered that that £250 a week means kilowatts, and revenue from kilowatts for current, when Boards and Committees realise what this means in revenue, and that they will be able to make up for their loss in lighting in that way, I do not think they will be content to pass it on one side and leave it alone. The proceeds from it are quite sufficient to cover the whole of the cost of business getting of the department. Mr. Seabrook.

Mr. J. S. Dow: I quite agree with anything that can be done to induce the consumer to regard his light, as Mr. Wordingham said, in the same way as his water supply. In spite of the admitted present obstacles we may hope eventually to see realised an ideal state of things according to which light, like water, air, or food, would be regarded as a necessity and made use of in the same free way. Unfortunately, people have hitherto been inclined to grudge the amount of light they use, though the greater efficiency of the metallic filament lamp seems Mr. Dow.

Mr. Dow. to be leading to a higher standard in this respect. This is a tendency on which not much has been said this evening, and yet it is one which should help to smooth the path of the supply companies, who fear a loss of revenue owing to the extended use of the new lamps. I was speaking to a representative of one of the leading companies on this subject recently, and he told me that lamp-makers were beginning to find that there was not the demand for small candle-power units that might have been expected; that the public had already began to ask for and expect the higher units, and were dissatisfied with metallic 16-c.p. lamps, when they discovered that they gave no more light than the 16-c.p. carbon filament lamps had done. His firm had brought out a metallic filament 16-c.p. lamp, but found, after a trial, that consumers almost invariably demanded lamps of about 25 candles or more. Perhaps other lamp-makers could bear this experience out.

I have noticed, in my own house, how the desire for brighter illumination has come about since we began to use metallic filament lamps. Some rooms, in which no change has been made (but which were previously considered quite adequately lighted), are now considered much too dim. I notice, too, that even a room which is apparently adequately illuminated comes to be considered dim by contrast if adjacent rooms are yet more brightly lighted. For instance, in my library the illumination on the table is well over 3 foot-candles, which would probably be considered quite enough. Yet people coming in from the somewhat extravagantly lighted drawing-room occasionally complain of the light. All this suggests that a higher standard of illumination may be expected to result from the use of the new lamps. Greater generosity in this respect will have, at any rate, one advantage. It will enable the consumer to acquiesce in the relatively small loss of light involved in effective screening, on which, as Mr. Cooper has just said, it is particularly desirable to insist in view of the great intrinsic brilliancy of the metallic filament.

Next I may refer to what I regard as one of the most interesting suggestions in this paper, namely, that supply companies will gradually tend towards undertaking the sale not of electricity, but of *light*. We must naturally expect that such a system will only come about very gradually, and probably many of the difficulties which we perceive so clearly at present will be smoothed away in time. But it will probably be realised eventually that a company that undertakes to sell light must also be prepared to *measure* light. After all, the present systems of charging for electricity have at least this merit, that the consumer knows that the amount of electricity he used was measured by a meter. He may or may not distrust its readings, but there is a measuring instrument to which to appeal. In the same way, if a company says to the consumer, as the authors suggest, "Come and look at this room lighted electrically, etc.," it should, one would be inclined to suppose, also be prepared to demonstrate by actual measurement that the illumination is as satisfactory as that by an alternative system. And

supposing that the consumer eventually takes up electricity, he might naturally expect to have some means of ascertaining, after a given interval of time, whether he is still getting the illumination which the company agreed to provide. Mr. Dow.

The experiences in my own house to which I have referred seem to suggest that ocular demonstrations, unsupported by measurements, may easily be fallacious. If I understand the authors correctly, they, while desiring to compare the costs of gas and electric lighting on the basis of the same effective illumination, assume the 25-c.p. glow lamp to be equivalent to "the so-called 60-c.p. gaslight," and I cannot help thinking that the conditions underlying such a comparison must be a little vague. Of course, it should be realised that there are so many factors entering into the illumination of an interior as to make the problem of charging on the basis of guaranteed illumination a somewhat complicated one, but I sympathise with the system as logical in theory, and hope that we may soon see our way more clearly to its practical realisation. I should also like to know on what grounds the authors come to the conclusion that no gas company could afford to adopt such a system of charging as they advocate. This afternoon I had a conversation with a prominent representative of the gas industry on this subject, and was informed that, as far as lighting was concerned, a gas company could afford the method perfectly well, but that there was little inducement for the gas industry to take up such a system when they had already such a convenient and simple one in use. I understand that in the early days of gas-lighting, before the measurement of gas consumed had become a practical process, a system resembling that of the authors was generally employed in the gas industry.

With regard to possible methods of preventing consumers inserting lamps of higher consumption than contracted for, it may be of interest to mention the method of the Rheinisch Westfälische Elektro-Sparlicht Gesellschaft of Essen, in Germany, where systems of the kind advocated by the authors are used in some localities. This company supplies small transformers for each individual lamp, which are ornamented with a brass or bronze finish and form an essential portion of the fixture. Lamp-holders of several sizes corresponding with the capacity of the transformers are used, and lamps with appropriately sized caps are provided, so that the consumer cannot, without altering the fixture, insert a lamp of more than a certain consumption.

Mr. H. I. Lewenz: I should like to draw attention to the authors' remarks on page 62: "Under an equitable tariff the cost of short-hour lamps to the consumer might possibly be increased, but that of long-hour ones would be greatly reduced. This might perhaps result in the loss of some consumers who at present do not pay their proper contribution, but would be no detriment to the undertaking." I do not think that is quite the right way to look at it. I think that whatever we do we ought to encourage all classes of consumers. By encouraging every class of consumer the output will ultimately be increased sufficiently to reduce the cost. I think that in another direction a saving could be Mr. Lewenz.

Mr. Lewenz. effected so as to reduce the running charges. The present-day distributing systems are very expensive, and one of the advantages of the authors' suggestions for low-voltage transformers would be less expensive insulation for the cables in the houses, and the low-tension cables from the transformers. I think it would be a great advantage to have standardisation of the lighting voltage and frequency all over the country. In that case all kinds of fittings and wires for the low-tension side of the distribution would be more or less standardised, and we should be able to buy our wires, fittings, and accessories in the same way as nowadays we are able to buy steam barrel, gas barrel, and lead-water pipe, etc., all to standard gauge and in accordance with prescribed tests. Finally, it seems to me that a complete set of rules would be of great advantage if they could be so made as to be agreed to by every electric supply undertaking in the country, especially if they received the sanction of the Government. If those rules were cast in a form which was not too complex and made in such a way as to encourage the consumer, I believe the increase in the use of electricity for lighting would be so considerable as to make the cost infinitely less, and do away with many of the difficulties which are the subject of this discussion.

Mr. Moncrieff. Mr. K. A. Scott Moncrieff: I must confess I am a little out of sympathy with this paper, for I do not fear metal lamps, and I value a day load. I have had some experience of small provincial stations and gas engines, and the authors' suggestion appeals to me in the same way that it appeals to Mr. Wilkinson. I think it works in very well with the bulk of the lighting in a provincial town. The bulk of the demand is well supplied without many long-hour lamps, and I do not think any maximum demand arrangement is necessary. There is not the shop lighting at night which Mr. Seabrook dealt with, and I do not think there will ever be much of it in the smaller towns—the 10,000-light towns. But there is a good deal of all-day lighting in old-fashioned towns where there are houses with low ceilings and dark shops, and it has annoyed me very much to go along the streets and see gas burning all day long in those places. I think consumers of this kind could be secured by giving them a simple contract supply, leaving the short-hour evening lighting to be dealt with by meter, which is the most economical way of dealing with it. There are one or two matters in regard to the engineering details of the paper that I do not quite follow. It seems to me that the authors' estimate in Appendix B for a station of 10,000 lights assumes 240-k.w. maximum demand. For that purpose there are three 100-k.w. gas *alternator* sets. I have a good many small gas sets generating direct current. If I redesigned such stations I would put in fewer and perhaps smaller sets and larger batteries. I would not care to deal with 240-k.w. even direct current, with three 100-k.w. sets and no battery. Another point which occurs to me is that in connection with the distribution by means of single-phase alternating current at 2,000 volts, it might be worth while to consider 4-wire 3-phase distribution within the limits of low-tension

supply, and I think there would be very little difference in the capital cost of the whole undertaking. I would like to corroborate Mr. Wilkinson's figures regarding services. We have had no difficulty in doing a service with 10 to 15 yards' run of service cable for about £3. Mr. Moncrieff.

Does not this paper rather take us back to the old days? We have alternating current with house transformers, and a lump sum charged per lamp. Going back about twenty years, I can remember that when electricity was introduced a leading journal, which was then in its infancy, under the name of *Lightning*, brought out figures giving the comparative results of different stations—figures of merit. My station won the prize, our figure being 2s. a unit for generating costs. I did not want any undeserved honour of that sort, and I wrote and protested against the figure, saying that it was only 1s. 6d. a unit. The "worst" results were obtained by a station whose costs were 2½d. a unit. My company was supplying by meter, the other company was supplying on the contract system, and I think neither of us paid any dividends to our shareholders. Both stations are now supplying through meters, and are financially a success.

(*Communicated*): The whole thing is summed up in Appendix C. Under existing conditions a station serves 54,000 lamps, and shows a certain profit. On changing to a contract system the same undertaking can only serve 23,300 lamps, and increases its profits by only £159 after selling 448,000 more units at 0·44d. per unit. Had these units been sold for heating or power at 1d. per unit they would have earned £1,866 instead of £159.

Mr. FRANK RISCH: In the early days of electric lighting, as I remember it about twenty years ago, the great object was to cheapen the cost of production of the electricity with a view to encouraging consumers to come on. The cost of energy has been cheapened considerably during this period by virtue of more efficient plant, boilers, engines, and so on; and now that the metallic filament lamp-makers have helped us very considerably to reduce the price further there is a terrible outcry, voiced to a great extent in this paper, that the small consumers whom we have always been looking for—because we had most of the big ones in certain places—must be left alone because they are not remunerative. It is said in the paper, "Let the gas people have them or let them burn candles." My point is that I do not think we can legally refuse anybody however small he is. If one is working under Parliamentary powers one has to confine oneself to those conditions. Then as regards the actual measuring of the current, a consumer can insist on having a meter even if he has only one 8-c.p. lamp. We have not yet come to the end of this difficulty as regards the metallic filament lamp. I remember years ago, when electric light stations were first started, the output was rated at so many 8-c.p. lamps. The authors have told us that they know of a 16-c.p. 200-volt metallic filament lamp, and I take it that in another two or three years we shall quite easily get an 8-c.p, 200-volt lamp, so that about 50 per cent. of our consumers by and by will be small consumers. Then with regard Mr. Risch.

Mr. Risch. to the system of charging so much per lamp per annum, before I had seen the paper I was talking about the matter to an engineer at a station, and he said to me, "We are doing splendidly with a new system, and I believe it is a system that will last. We are charging 5s. or 7s. 6d. per lamp per quarter, and we are also charging 1d. a unit so as to see that the limit is not exceeded. We put a meter in and we charge 1d. a unit; we are really doing very well." I said to him, "I expect you are, but how long are you going to do well? You know the gas company are in the district, and they will probably make a canvass of your consumers and let them know they are being robbed." Mr. Wilkinson, who is one of the pioneers of the contract demand system, admitted to us to-night that the consumers were paying more, but that they willingly did so because they knew in advance what they were going to pay. I do not see very much logic in that. We all know that we have to pay our bills, and we prefer them to be as small as possible. With regard to the small consumers whom the authors do not consider worth having, look at them for the moment purely from a commercial point of view. Quite apart from the number of units consumed, I contend that in the near future these very small customers will be worth having, and it will pay us even now to put them in a good meter. We should not, however, put in a small meter (for 1½ ampere), but a 5-ampere meter, because I am quite sure within the next two or three years electric heating in various forms will be very much better than it is to-day, and then there will be a very great demand for it. I know as a positive fact that there are hundreds of thousands of little cottages which will not have electricity for the simple reason that they must have gas stoves. When we can make an electric gas stove, if I may use the term, that is to say, an electric stove as cheap to buy and as efficient to use as a gas stove, I think you will find that you will be able to get a very large number of these small cottage properties on your accounts as profitable consumers which now you say you do not want because they are not remunerative. I suggest that in these small cottage properties a 3 to 5-ampere meter will be as good in several years' time as it is to-day, so that the supply company will not have to buy other meters, which would only tend to complicate matters. Another thing which has hindered electric lighting to some extent is that electrical engineers are rather too scientific and not commercial enough. A speaker just now stated that he was talking to a representative of a gas company who said they could do anything that the electric light people could, and I believe it. The gas companies do not scoff at the small consumers, they put them in a penny-in-the-slot meter, and they are making a lot of money out of it. The dividends of the gas companies in the last few years have gone up by leaps and bounds because they have taken the small consumers that we object to. Another point with regard to small consumers is, Why should small buyers of any sort be penalised merely because they are small buyers? I consider that is bad business policy. Providing we get all the small man's business, why should not

he have as good terms as a large man, whether we are manufacturing stock or electricity? The plant is there, the output goes on, and why not sell as much as possible—some to the large people and some to the small at the same prices? Then there is one other point I would like to raise, because I rather think it has a bearing on the subject of this paper, namely, the imposi ion of the regulation by the Local Government Board insisting that meters be purchased out of revenue. I do not see the reason for that at all; I think it is exceedingly hard on the central station engineers, especially the small ones. For instance, a municipal engineer may add fifty new customers to his undertaking; his committee meets, and he says, "We have put on fifty new consumers." They ask, "What is the increased revenue?" and he replies, "There is no increased revenue, because I have had to buy out of my revenue fifty meters for these new consumers." I think the Institution might very well approach the Local Government Board to get that matter remedied, because meters to-day are so good and reliable that they can very well be considered as part of the plant and they last as long as some of it. They are not like some of the meters of days gone by, which were inefficient and had to be scrapped before they had been in use for very long. Mr. Risch.

Mr. H. HIRST: The authors' excellent paper deals entirely with the tariff from the station point of view, but at the request of one or two previous speakers I explain the lamp-makers' point of view. I can only repeat in connection with charging what I said eighteen months ago, that there is no need for panic measures—no need to create uncertainty in the consumers' mind. The very interesting figures that Mr. Wilkinson has given to-night show that my remarks were justified. He has told us that there has only been 2 per cent. difference in the revenue. I think I ought to say from the lamp-makers' point of view that this is due to three reasons. First of all, in spite of the ability of the lamp-makers to make 17-watt lamps, it is surprising how the demand throughout the country is increasing for large candle-powers. The metallic filament lamp was introduced as a high candle-power lamp; it gave better light, and I think the better light had quite as much to do with its rapid acquisition of popularity as the actual saving in current. The second point I would like to mention is that the attack on the 26 million pounds' revenue on which the gas companies pride themselves, and on which the authors dwelt in their previous paper, is being waged very successfully. We have proofs that gas consumers rapidly come over to the side of the electric lighting, and if a cheaper wiring system and a better supply of lamps is available next year we shall show greater progress in that direction. The third point I should like to bring up, which explains Mr. Wilkinson's figures, is one that I am rather surprised has not yet been mentioned. I find that there must have been a considerable revenue to supply companies, through the prolonging of the period of the peak load, thus improving the load factor of the station. The human machine is a very automatic machine. We turn on the light when we find the artificial light is Mr. Hirst.

Mr. Hirst. better than the daylight. I have noticed that lights are generally turned on very much earlier than formerly, and that must make a considerable difference in the future revenue of the supply companies.

Mr. Tuckett. Mr. P. D. TUCKETT: Before the authors are called on to reply I should like to appeal to them to explain to the meeting how they propose to enforce a fixed charge. I take it every one present is generally in favour of some form of fixed charge, but seeing that the consumer has the option of the flat rate I do not follow how the fixed charge is to be enforced.

Mr. Robinson. Mr. I. V. ROBINSON (*communicated*): I wish to make a few remarks on this paper from the consumers' point of view. It does not appear to me to be correct that any one should set to work to consider the present aspect of electric lighting by itself without taking into consideration the other domestic uses of electricity which have been brought so much before our notice within the last six months. All central stations, particularly those in a purely residential district, are compelled to find new outlets for their current owing to the increased use of the wire-lamps, and there is a large field before them in the ordinary household. I do not therefore think that it is possible to devise a satisfactory tariff if only the lighting is considered. In Messrs. Handcock and Dykes' paper great stress is laid upon the advisability or necessity of obtaining long-hour consumers at the expense of the more numerous short-hour consumers. Would it not be better, by some means, to change the short-hour consumers into long-hour consumers? On page 59 reference is made to the average number of units consumed by the lamps connected to the system. This hardly seems to me to be a fair criterion for comparison, as, in the majority of houses there are a considerable number of lamps connected but only used very occasionally. This should not be the case where the houses are free-wired, but where the landlord wires the houses there should be no obstacle to his putting in a large number of lamps, but if a fixed charge per lamp per annum were made the landlord and the tenant would very considerably restrict the number of lamps in the house. Possibly the fact that Mr. Wilkinson has adopted a similar system in Harrogate may account for the fact that I have noticed in the living rooms of friends in that town that a very low power lamp is generally in use. In some cases they have a 25-c.p. lamp in a dining-room, and in my opinion this is far too little.

In the paper the authors refer to a particular London suburb, and I have reason to believe that I am a consumer in the district referred to. I find that in one year I consumed 206 units at a total cost of £4 13s. I have fourteen lamps in the house, but on an average only use about six. The units per lamp connected are therefore only 14·7, but per lamp in average use 34·4. The revenue per lamp connected is 6s. 8d., but per lamp in average use 15s. 6d. The average hours per lamp connected are 420, but per lamp in average use 980. On page 62 the authors suggest throwing overboard the short-hour consumer, but I

Mr. Robinson.

think that the electricity should be available in every household similarly to gas and water, as undoubtedly there are more short-hour consumers than long-hour consumers.

A standing charge of £17 per kilowatt on the consumers' demand is extremely high, and in the suburb to which I have referred I note that the total standing charges for a certain year were £6,998, whereas the maximum demand on the feeders was 690 k.w., so that in this case the standing charges are slightly over £10 per kilowatt. Assuming that the figures given on page 62 were applied to lamps which burned 8,760 hours per annum, the total annual cost per lamp would be 16s. 8d., and this would be equivalent to £28 4s. per kilowatt-year. This figure is far too high, and probably the authors would not claim that they could not supply the extra units at a less charge than 0·4d. if the load factor be increased from 22·9 per cent. (2,000 hours) to 100 per cent. I think a good deal could be done if current were supplied at a fixed price of £20 per kilowatt-year, the current to be used for whatever purpose the consumer desires to have it. On page 63 the authors state that they think that 12s. per 30-watt lamp per annum would be a reasonable price, and it is interesting to note that this is equivalent to £20 per kilowatt-year if by "continuous supply" they mean 24 hours per day; 10s. per annum for a dusk-to-dawn supply is far too expensive. Electricity should be on tap at any hour during the day, just as gas and water are, and it would be fatal, in my opinion, if any station proposed shutting down during the day. There would be no great saving owing to the fact that a certain amount of labour would have to be kept at the station in order to start up the plant during any periods of unusual darkness during the day. On page 64 the authors say that they should set out to sell light and not electrical energy. This is not correct in my opinion. No restriction is made by the gas company as to the use to which the gas should be put, and in order to meet the gas competition electricity departments must be on a similar footing. On page 67 there is suggested a means of overcoming the objection that consumers would have to pay, say, 12s. per annum for every lamp they have installed, but it is not quite clear how this will work. What is there to prevent the consumer stating that his maximum number of lamps he wishes to use at once will be, say, six, and afterwards using eight or ten together? With reference to the remark on the same page as to the impossibility of the gas company making a fixed charge per annum, this is already done by the Water Board for the supply of water, and probably could be done by electricity.

In my opinion the future of all power stations in residential districts lies in the supply of electricity for other domestic uses. The best method, as far as I can see at present, is for the consumer to instal a water-heater such as the now well-known Therol heater, and to take current from the heater when required for lighting, cooking, or any other domestic use. What current is not required for lighting, etc., would be absorbed in the Therol heater. This would give a constant demand at the power station, improve their load factor, reduce standing

Mr. Robinson. charges, and in every way improve the whole situation. This could probably be carried out with economy at £20 per kilowatt-year, but any higher charge than this would prevent the development from taking place.

Mr. Higgins. Mr. C. HIGGINS (*communicated*): It is exceedingly interesting to hear direct from the engineers of the various supply undertakings the methods they have adopted or intend adopting to combat the decrease in load which, it has been suggested, will follow the introduction of the metal filament lamp. The various methods appear to be a benefit both to the consumer and supply company, and certainly reflect considerable credit on the latter. There has recently come to my notice, however, a method of dealing with large consumers which will probably drive them to desperation, or to gas. A certain supply company actually gave notice to a certain large consumer that they would withdraw all the concessions made to them in consequence of their large consumption, and would readjust their tariff, if metal filament lamps were introduced. This is an attempt to throttle the new lamp industry in its infancy, and can certainly do no good to the lighting industry, when it has just "drawn its second wind" in the race with gas.

Mr. Davie. Mr. J. F. DAVIE (*communicated*): The information given by the authors is useful, but the problem of electricity supply as regards London must be looked at in a much broader sense than the problem of dealing with small local installations. The question before us is not merely the supply of light. To cheapen the supply we must look to selling electricity for all sorts of purposes. We have to get our plant used for much longer hours and to spread the charges over a much greater number of units. This is impracticable if we consider lighting only. Something in the direction the authors recommend is already being done, but by itself it will not do much, and in the great majority of cases fixed charges for lighting are impracticable. The most we should be likely to do, even if we could make it universal, would be to increase the load factor from 13½ to 15 per cent.; but by spreading the use of electricity to heating, cooking, and power, load factors up to 30 or 40 per cent. are probably obtainable. For every kilowatt connected for lighting 5 to 10 k.w. could be connected for other purposes even in a private house, and its peak spread over five or six times as many hours as in the case of light. Now we shall not obtain this result by means of a fixed charge, because if fixed high enough to protect the supply undertaking no one would use it, and if fixed low enough to attract the consumer the waste would not only kill the profit but lead to disaster. A low flat rate is, I believe, the only possible general system for this kind of business—a rate sufficiently low to make it worth the consumer's while to use electricity freely. This is possible so long as the supply company is supplying light, because the additional units for other purposes can, as the authors show, be supplied at a very low rate, there being no extra expense for administration and very little for capital. When, however, the consumer obtains his light elsewhere, either from gas or from his own plant or from another company, both capital and

administration expenses have to be taken into consideration, and a low rate is impracticable. Mr. Davie.

All those interested in the industry, whether as consumers, contractors, or supply undertakers, should study this question on broad lines. If, as I believe, the use of electricity in the future for purposes other than lighting will enormously exceed its use for lighting, we must do everything we can to encourage it. The rate of charge must be low, the apparatus reliable and cheap, and the wiring good and inexpensive. In my opinion it is only possible for the price of energy to be low where the whole of the supply both for lighting and other purposes is taken from one source; and, if I am right, those who recommend consumers to try and take the cream of both where there are two supplies instead of sticking to one are doing them and the industry a disservice.

Mr. A. J. CRIDGE (*communicated*): Papers such as the present serve in after years to indicate the position of electric lighting at a given point of time. Mr. Cridge.

When we come to the methods of charging, there is much to be considered. I have had some experience of a contract rate, which I will state as briefly as possible. A certain trading firm were formerly consumers of the undertaking with which I am connected, and used, at ordinary rates, a definite average number of units yearly. They put in their own plant, and after a time it broke down, and they came to us to help them. The engine which drove the plant also drove a number of grinding shops, and motors were put in to take this load. We were in a position, then, to estimate fairly closely the amount which would be taken for power, and the requirements for lighting were based upon previous consumption, which, we were assured, had not been exceeded when their own plant was running. However, at the end of the year we found that more than three times the estimated units had been used for light; so I do not look with favour upon a fixed rate of charge irrespective of the use which is made of the current.

Further, a system of charging based upon limitations does not commend itself to me. A fixed charge per lamp installed, with a small price per unit, discourages the installation of electric light in bedrooms. The maximum demand system is useful as indicating the lines along which we should think, but I believe most engineers are agreed that it is beyond the grasp of the average consumer. I think the contract demand would be nearly as bad. Flat rates have the great merit of simplicity, but when there is light at 4d., power at, say, 1½d., and heat at 1d., the householder who has lighting, radiators, and a small lathe with which he amuses himself, is obliged to have three meters. So we are compelled, if we wish to get more revenue out of existing services, to get some method of charging which will permit of the connection of all kinds of apparatus to one circuit, and at present I think the Norwich system, due to Mr. F. M. Long, is worthy of investigation, more especially for private houses.

The use of special lampholders could not, I fear, be enforced. I

Mr. Cridge. also do not think that local contractors would be very anxious to assist an undertaking to control the sale of lamps within its area. The subject of charging for electricity is, perhaps, the most important in the domain of electricity supply, and one could speak at great length about it. At present agreement between engineers seems rather far off, but that should not be allowed to discourage careful thought upon the matter from all who are interested in the progress of electricity.

DISCUSSION AT BIRMINGHAM, December 1, 1909.

Mr. Forster. Mr. LINDSAY FORSTER: I am in an almost unique position, having in my district gas works as well as an electric power station, and so far it has never been worth while to put in electric light under local conditions. But owing to the metallic lamp having become practically available, there is no doubt that the electric light has passed beyond the stage of luxury and that the wire lamp will be a very great factor in popularising the supply. We have many instances of commodities being sold by rate. If we turn our minds to one of Birmingham's departments we find that the supply of water is almost entirely by rate, and I do not see why we should be so very far from that position with electric lighting, except that wiring lends itself more readily to illegitimate uses; but that could be dealt with in a suitable manner if such a tariff as Mr. Handcock suggests were introduced.

Mr. Orsettich. Mr. R. ORSETTICH: My point of view is different from the one taken up by the authors; as I am considering their proposals from the point of view of the consumer, whom they pictured in perpetual opposition to the station engineer. To begin with, I do not see what class of consumer they wish to supply under their tariffs. If the consumer is one who at present uses the "penny-in-the-slot" system for his gas, he will not be in a position to pay 15s. or 20s. down each quarter for his electric light. We must remember that it is only the penny-in-the-slot meter which made the expansion of gas possible in competition with the oil lamp. And if a prepayment meter should have to be adopted the whole system explained to us would be of no use. The second point is in connection with the number of lamps. If the consumer had only two or three lamps, then he requires the penny meter; but if he is a better class consumer, with ten or fifteen lamps, I do not agree with the statement that 80 per cent. of the lamps installed are switched in at the worst time for the station. From my personal experience I believe 30 to 35 per cent. is the correct figure. Thirdly, as to the charges of the stations: it is quite true that at the present prices, and with metal filament lamps for some stations, it cannot possibly pay to increase the number of private plants. From my experience, to bring the charges as far as possible into line with the cost of gas lighting, between 4d. and 4½d. per unit should be charged, whereas the Aston Corporation charges only 3d., which is too low. The electric light in Aston therefore costs already much less than gas light, so that the

estimates given in the paper, so far as Aston and Erdington are concerned, will be of little use. Mr. Orsettich.

Then, as to the question of a fixed charge per lamp. If a charge of 10s. or 12s. per lamp per annum should be applied, I am afraid it would have the effect of stopping all extensions of private lighting. For average houses, with ten or fifteen lamps, it would be impossible to pay at a rate of 12s. each, as it would be far too expensive. At present, the Aston charge works out at something like 3s. per lamp per year, without taking into account the lamp itself. Assuming the life of the lamp to be about 1,500 hours, it will last at least three years, and therefore the charge for renewal is hardly appreciable. As, further, this consumer burns only one-third of all his lamps at any time, I believe he would consider it extremely unjust to be charged 12s. for each lamp, whether burning or not, and the result would show itself in a very much reduced number of houses connected up. Another disadvantage would be that it would handicap the extension of the lighting in the house. There is no doubt that whenever a consumer puts down a certain new plant he is at first rather doubtful about it, and careful about the expense he is put to. He will start with a few lamps only, and afterwards, if he finds the charge is moderate, he will extend the lighting to the most suitable parts of the house. This would all be done away with if there should be a fixed charge per lamp, whether he uses them or not. Another point, which also would come in, would be the question of candle-power, and here again we meet the question of continuous expansion. A consumer begins with 10-c.p. lamps, but after a short time replaces them with 16, 20, 25, or possibly 50-c.p. lamps. All this would be impossible if a fixed charge based upon candle-power were made from the beginning. Against all this, I realise that the position of some central stations is very unfavourable at present, and that something should be done to improve it. My point of view is that before going to canvass for the consumer who puts down two or three lights, there is plenty of scope—much more than one realises—for the consumer who puts down 10 or 15 lamps. The question of canvassing is important, although up to the present the stations have been able to do without it. In America the canvasser is a very important member of the central station staff. Further, there is a very large scope for expanding the use of electricity in other directions besides lighting. To mention only a few of the possibilities, there are small motors for domestic purposes, fans, flat irons, heaters, cooking appliances, vacuum cleaners, and, finally, even vibrators. Each and all of these, from the reports appearing in the technical press, are being extensively adopted in the States, and represent a very large percentage of load, coming on at very favourable periods of the day, and there is no doubt that it would be worth while for any station to push such appliances amongst their customers. This seems to me very much more open-minded than to propose restrictive measures, which, at all, could only afford a temporary advantage, and would in the long run most certainly cripple an important section of the industry.

Mr. Railing.

Mr. M. RAILING: So far, we have discussed this paper from the consumers' point of view, but it would, no doubt, be interesting to us to hear the opinions of some of the station engineers. When Mr. Handcock read his first paper a year ago it occurred to me that he was looking at the advent of the metallic filament lamp with some mixed feelings. He pointed out correctly at that time that the appearance of this lamp meant considerable reduction in the revenue of many of the existing stations. Some of the lamp-makers, however, expressed their strong opinion that the additional number of new customers attracted by the lower current consumption would easily make up for the decreased revenue, and now that we have had, for the period of over a year, the extensive use of the metallic filament lamp in many of the stations, it will be rather interesting to know from those who come daily into contact with this problem, whether the increased applications for electric light have in some way made up for the prophesied outfall in the revenue accounts. My experience of metallic filament lamps rather makes me believe that in many stations the lower consumption of current has induced many people, who, up to now, had been wavering, to adopt the electric light, and the further fact that in many cases larger candle-powers have been installed must have made up for the fall in revenue which was expected. Consequently, therefore, I would like to hear from some of the station engineers present if they can give us any indication whether the advent of the metallic filament lamp has helped to extend and increase the output in their respective stations.

I am also of the opinion that it should be the endeavour of the station engineers not to try to secure slightly increased price from the consumers, but to bring in more consumers, and in this direction surely the metallic filament lamp has been a useful help. If manufacturers succeed in producing a small candle-power metallic filament lamp, I feel sure that it will be an additional inducement for many people to avail themselves of electric light, and the large number of additional connections will, in my mind, make it unnecessary to adopt the suggestion laid down in Mr. Handcock's paper.

Mr. Milnes.

Mr. W. E. MILNES: With regard to the question of revenue, so far as Birmingham is concerned, the growth in revenue from current sales on lighting only is approximately as follows: In one year we had 5 per cent. increase, the next year 10 per cent. increase, and the next year about 17 per cent., and this year about 27 per cent., the increases being based on the first year's revenue, so that the curve is a fairly straight one. Against that one must remember that though we have only a small increase of current we have some increase in candle-power. I suppose two-thirds of our lamp connections are metallic filament lamps. Therefore, the candle-power connections are much higher than they used to be. That is about the comparison which holds good in other towns. I think the system of charging so much per annum per lamp is one that might be applied with caution to a certain class of consumers. Where I was some years ago, I took on quite a lot of

houses at a small fixed charge per house. We had a block of 72 houses and charged them 6d. a week in summer and 1s. in winter, paid in advance strictly. We had one service for every 6 houses, and one main supplied the whole 72. We had a meter in the main so that we had an accurate register of consumption, and after paying capital charges we found the revenue on the current supplied worked out at 1½d. per unit. We had five 8-c.p. carbon filament lamps per house. In other parts of the same town we tried the same system in smaller blocks of half-dozen houses. But these houses were very old and were frequently vacant. We did not make quite so much on these, and one ingenious consumer constructed radiators, which he connected and so defrauded us. Sixpence in summer and 1s. in winter did not work out so well on such supplies. We have experimented in Birmingham in the lighting of small houses with prepayment meters. After about eight months' running the consumers are quite satisfied. We have charged 5d. per unit, which covers service charges, meter rent, and cost of current. The consumer is satisfied because he gets a better light than previously with a 60-candle gas mantle, and the cost of the current is lower than the cost of the gas for the same light. This is a scale of charges and a system of supply which may probably be developed here. It is quite suitable to our work, and for artizans' dwellings. The great thing is to demand payment in advance from these small houses. Mr. Milnes.

Mr. W. FENNELL: I have been astonished at the view taken by station engineers, who seem to think that if the revenue for one year shows signs of coming down, the end of all things has arrived. It seems to me we ought to be prepared for one or two lean years, because the advertisement caused by reduced accounts will cause a subsequent boom. Some undertakings spend sums of money on Publicity Campaigns, but I prefer to consider reduced accounts the best advertising system, because every consumer becomes an enthusiastic canvasser. In this connection I can supply some figures. I thought it would be interesting to take the last Saturday evening in November at the Wednesbury station for the last five years. On Saturday evening the load is purely lighting, so the results are free from the disturbing effects of motor load. In 1905 there was a considerable increase over 1904; in 1906, not a very large increase; in 1907, a considerable increase; 1908, however, was lower than 1907; but in 1909 the curve shows that the output for lighting was double that of 1908. It is clear that the 1908 drop has had a very large advertising effect, and that the reduced revenue caused by improved lamps has paid us very well indeed by causing a rush of new consumers. Mr. Fennell.

With regard to the securing of new long-hour consumers, I would direct attention to one very desirable field that has hitherto not been touched properly, I mean the public-house. In the Black Country, there are an enormous number of public-houses which have not been secured with carbon filament lamps at ordinary prices. I do not think I am giving any secret away when I say that the big brewery com-

Mr. Fennell. panies are now seriously considering the adoption of electricity for lighting throughout their houses. During this last week I fixed up with one company for two houses, and another one for three houses, and we have several other cases in which we are giving trial supplies with promise of very good results. We might make up our minds that the metallic filament lamp should not cause a scare and lead us to upset the whole system of charging, but that we shall be able to extend enormously the field of electric lighting by its use. With regard to the contract system, I do not know whether it has been considered that it would be a tremendous change in the thinking habits of the population. People are used to buying gas by the thousand, most dry goods are bought by the pound, liquids by the pint or quart, and it is in man's mind to buy by measure. To tell people to buy by so much per lamp per year irrespective of quantity used conflicts with their ideas of business. A simple contract system creates dissatisfaction, especially in small towns. The shopkeeper takes it as a grievance that his next-door neighbour, who keeps open longer, pays the same for his light. In other words, the short-hour consumer would have a grievance against the long-hour consumer. There is no serious necessity for avoiding the expense of meters. We have now fairly good meters and can buy them cheaply, can, in fact, get meters for small consumers for as little as 10s. 6d. I remember in 1893 or 1894, I was at a small station in the West of Ireland, and we had this contract system there. It was necessary because we had to pay £5 each for meters. It has already been mentioned in this discussion that with prepayment meters the contract system cannot be maintained. Our experience with rows of small houses is that we have found it very necessary to get payment in advance. If the landlord can be persuaded to add a contract price to the rent I must admit that it does away with one objection to the rental system of charging. I do not know whether it has been considered by the authors that if some "stupid" consumer insists upon buying by meter, he has a right to be so supplied. Of course, one might advertise a charge of 8d. per unit, but in that case our gas friends would secure a tremendous advertisement by public comparison of gas at 2s. 6d. with electricity at 8d. per unit.

In any case, the expense of meters and the work involved would be nothing to the complication of house-to-house visits that would be required under a contract system. One would have to make surprise visits at all sorts of times to see whether the consumer has changed from 16 to 32 candle, and so on. I do not see that it is necessary to go in for this inquisition, it will not be popular, and the metal filament lamps, with electricity at the old rates, will provide a very good revenue in the end.

Messrs. Handcock and Dykes. Messrs. HANDCOCK and DYKES (*in reply*): In the first place, we wish to express our appreciation of the reception that has been accorded to our paper, and specially to thank those who have come from a distance to speak.

It was particularly gratifying to us to hear Mr. Wilkinson's remarks,

because he is in a position to give, first hand, the results that he has obtained personally from putting the contract system into effect at Harrogate. Messrs. Handcock and Dykes.

It has been suggested that our intention is to run undertakings entirely on the contract system. This is not so. Our point is that, thanks to the introduction of the metallic filament lamp, we are now enabled to invade a large territory previously occupied entirely by gas undertakings, and that we are of opinion that a useful weapon for the purpose of the invasion will be our contract system, which holds out considerable inducements to the consumer, and at the same time insures the supply authority against loss.

As to whether the stations which thus adopt this system for the purpose of attracting long-hour gas consumers, afterwards extend the system to their existing consumers, is a matter which local conditions, time, and experience alone can decide.

One speaker was apparently under the impression that we advocated the use of 25 volts. This is, of course, a misapprehension, and further perusal of the paper will make it clear that our remarks apply to supplies at normal voltages. We do say, however, that in certain cases it will pay to put in a double-wound transformer on alternating-current systems to reduce the pressure to 50 or 100 volts, using earth return wiring on the consumers' side instead of an ordinary two-wire system.

As regards the question of overhead wires, as far as we are aware, the Board of Trade have never, consistently with public interests and existing legislation, done anything to bar progress in this or any other direction. The objectors are generally the local authorities or the inhabitants of the districts concerned.

We appreciate the compliment which Mr. Wordingham pays us in stating that we are rubbing in a fact which nobody can get over, but we do not follow his argument relating to the incident of the introduction of meters by the London Electric Supply Corporation, as, in the light of his earlier remarks, the flat rate, which was in use at that time and did not differentiate between the long-hour and the short-hour consumer, was a ludicrous one. We do not share his objection to the supply of lamps by the company at a profit—that is to say, at retail prices. Indeed, if our memory serves us rightly, the makers of these lamps stipulate that they shall only be sold on this basis. Does Mr. Wordingham suggest that a retailer in retailing lamps at retail prices is receiving more from the consumer than he is entitled to?

We would remind Mr. Wordingham of Mr. Trotter's remarks in this room on the question of legality of various methods of charging. He has probably overlooked the fact that we propose to proceed by agreement. Any consumer who does not find the contract system advantageous is entitled to be supplied on a flat rate, and in this latter event the undertaker is not allowed to prescribe any particular form of burner.

There is nothing inconsistent in this, as the contract system is intended for long-hour consumers who would find the flat rate come out more expensive,

Messrs. Handcock and Dykes.

Mr. Wordingham's reference to the town in which he lives is apt and instructive. His fellow citizens do not, however, follow his good example in the matter of electric heating, as the whole receipts from heating amount to 1 per cent. of the total takings of the station. Consumers who give such meagre recognition to facilities that the Corporation brings to their very doors, could not complain if they experienced the fate which Mr. Wordingham contemplates "of shivering in the day-time." We do not anticipate, however, that the contingency will arise.

Several speakers appeared to be under the impression that we advocated the principle of giving no supply during hours of daylight. This is a misapprehension; our suggestion is that in certain districts and under certain conditions, where stations cannot profitably be run the twenty-four hours round, the financial prospects may be greatly improved by a dusk-to-dawn supply.

We do not anticipate any great difficulty due to the consumers under the contract system putting in a higher candle-power lamp than they have paid for. Apart from the question of special lamp-holders, it constitutes a theft of electricity, and that is a felony.

We are in sympathy with the suggestion that it would be desirable to sell the additional 448,000 units (allowed for in Appendix C) at 1d. per unit for heating and power purposes. But how many suburban stations of this size have any prospect of selling even a fraction of that quantity for heating and power purposes unless there is a tramway in the district; and what is to prevent the load from overlapping the peak of the lighting load?

Permit us to remind you that the "Contract" system as advocated by us is not a new thing, and has stood the test in connection with water supply.

It has been suggested by certain speakers that the enforcement of the system might result in a certain loss of dignity to the undertaking. As far as we are aware, Water Companies supply on the basis of a fixed sum per annum and do not experience any difficulty in that respect, and they have certainly achieved economy of administration and give satisfaction to the consumers.

We are sorry that Mr. Wilkinson is not here to-night, as he could tell you how very successful the system is at Harrogate.

With reference to the difficulty of consumers inserting higher candle-power lamps than those they are paying for, this, after all, is not such a very serious matter to deal with, as it is theft of electrical energy, which is a felony, and can be dealt with accordingly. It is surely just as difficult where special lamp-holders are used, to steal electricity this way, as it would be at the present moment to take a tapping from the supply side of the meter.

At the risk of repeating what is already in the paper, as the discussion rather suggests that we have not made ourselves quite clear on one or two points, we wish to say that we do not advocate that the existing tariff, whatever it may be for any existing supply station,

should be abolished. We do advocate, however, for the purpose of breaking fresh ground outside, that the figure at which you can give consumers a supply on the "contract" basis should be determined, and that light should be offered at that price to every gas consumer who is at present paying more than that for illumination by means of gas. It will probably work out at about 12s. per 30-watt lamp per annum. Messrs. Handcock and Dykes.

We would also remind you that if the scheme is to work successfully, it is desirable that not only should the consumer pay for his own lamps, but also that he should buy them from the undertaking, so that there should be a check on what is going on.

In certain cases arrangements are being made to collect the lighting charges with the rent of the house, which is a convenient method of dealing with the question.

It was suggested by one speaker that there is a vast unexplored field for electric light undertakings, due to the fact that the art of canvassing has been but imperfectly studied. That may be so, but apart from the direction indicated in the paper, our own opinion is that the field has been very thoroughly explored indeed, and that the canvassing departments of the electric light undertakings are conducted in a thoroughly energetic manner.

We congratulate Mr. Fennell on the success that has attended his efforts with metallic filament lamps, and hope that it is the forerunner of similar successes in the case of many other supply undertakings.

The President. The PRESIDENT: Before I call upon you formally to record a vote of thanks to the authors, perhaps you will allow me to say that a system similar to that advocated by the authors is already in use in at least one place to my knowledge, and that I have had personal experience of it. That place is a little town in upper Italy. The consumer contracts with the company for so many amperes of current at a fixed voltage. The fixed price paid is considerably smaller than what would have to be paid under a flat rate. If you wish to exceed the amount of power contracted for you can do so, and no blinking takes place, but you have to pay for the excess which alone is recorded on the meter. In my case the contract was for 5 amperes at 160 volts. I could exceed the 5 amperes, but then the meter would register the excess. Most consumers in the district are supplied under this system and find it quite satisfactory. The fact which was mentioned by Mr. Wordingham, that John Hopkinson was the first to suggest it, is, I consider, the greatest compliment which could have been paid to the authors. I am told by one of the authors that they are putting in 10,000 lamps in London on their system, and I am sure we all wish them a very successful result of their bold experiment. I have now great pleasure in calling upon you to record a hearty vote of thanks to the authors for their paper, which should do a great deal to popularise domestic lighting further.

The resolution was carried with acclamation.

[*The discussion at Manchester will appear later.*]

MANCHESTER LOCAL SECTION.

INAUGURAL ADDRESS BY THE CHAIRMAN,

S. J. WATSON, Member.

(*ABSTRACT.*)

(*Address delivered October* 22, 1909.)

I propose to-night to make a survey of various points of interest in connection with the development of electric supply undertakings during the past fifteen years. In looking backward one cannot help but be impressed with the remarkable growth that has taken place during a comparatively short period of time, and the tremendous amount of work involved in the equipment and setting to work of the various power stations with their distributing systems.

Complete statistics are unfortunately not available, as some undertakings will not give sufficient information to enable their returns to be included in the well-known "Table of Costs" published in the *Electrical Times*, but in order to illustrate the growth that has taken place I have prepared a table giving a summary of the records contained in issues of *Lighting* and the *Electrical Times* in 1894, 1899, 1904, and 1909, so that you will see, and, I hope, appreciate the improvements which have taken place during three periods each of five years.

It is no small thing to find that the amount of capital invested has increased from four to nearly sixty millions of money in fifteen years, but such a fact does not necessarily imply that the capital is being employed to greater advantage from the engineering or even from the financial point of view, and in order to show that progress has indeed been made, I have also shown on the table what the increase has been during each period of five years and the extra cost of dealing with such increase.

This method of ascertaining the cost of the extra units sold from year to year and also the extra capital charges incurred in supplying the extra units gives some very valuable assistance when working out the price to be charged to cover the cost of supplying large consumers. I have personally used this method for some years, and you may perhaps be interested to know that, applying it to the past seven years'

RECORD OF SUPPLY UNDERTAKINGS.

	1894.	1899.	1904.	1909.
Number of undertakings...	30	100	225	290
Capital expenditure	£4,472,925	£11,895,993	£38,284,458	£57,818,142
Plant installed	32,108 k.w.	112,631 k.w.	454,565 k.w.	795,036 k.w.
Increase in capital	—	£7,423,068	£26,388,465	£19,533,684
Increase in plant ...	—	80,523 k.w.	341,934 k.w.	340,471 k.w.
Capital outlay per kilowatt	£139	£105	£84	£72
Cost per additional kilowatt	—	£92	£77	£57
Maximum load	—	78,866 k.w.	269,680 k.w.	501,941 k.w.
Per cent. to plant installed	—	70 per cent.	59 per cent.	63 per cent.
Units sold	15,231,181	76,432,250	349,003,935	824,819,503
Increase in output	—	61,201,069	272,571,685	475,815,568
Per cent. increase...	—	401 per cent.	357 per cent.	156 per cent.
Units sold per £1 expended	3·4	6·4	9·1	14·2
Units per additional £1 expended	—	8·2	10·3	24·4
REVENUE	£392,077	£1,556,262	£4,763,111	£7,528,321
Per cent. to capital	8·7 per cent.	13·1 per cent.	12·4 per cent.	12·8 per cent.
Increase in revenue	—	£1,164,185	£3,206,849	£2,665,210
Revenue per unit ...	6·16d.	4·89d.	3·27d.	2·16d.
Revenue per additional unit	—	4·55d.	2·82d.	1·34d.
Working expenses	£243,021	£786,115	£2,334,088	£3,681,504
Per cent. to revenue	62 per cent.	51 per cent.	49 per cent.	49 per cent.
Cost per unit	3·82d.	2·47d.	1·60d.	1·07d.
Cost of additional units ...	—	£543,094	£1,547,973	£1,347,416
Cost per additional unit ...	—	2·13d.	1·36d.	0·68d.
GROSS PROFIT	£149,056	£770,147	£2,429,028	£3,846,817
Per cent. to capital	3·3 per cent.	6·4 per cent.	6·3 per cent.	6·6 per cent.
Increase in gross profit ...	—	£621,091	£1,658,876	£1,417,794
Per cent. to additional capital	—	8·3 per cent.	6·3 per cent.	7·2 per cent.
Load factor total output ...	—	11·0 per cent.	14·7 per cent.	18·7 per cent.
Load factor additional output	—	—	16·3 per cent.	23·3 per cent.

records of the undertaking with which I am connected, during which time the output has increased nearly tenfold, and large extensions have been carried out to plant and mains, I find that the extra generating costs amount to 0·293d. per unit, the extra capital charges on plant to 0·154d. per unit, the extra distributing costs, *i.e.*, repairs and capital charges on mains, etc., to 0·234d. per unit and the extra management charges to 0·087d. per unit, so that the total additional cost of supplying the extra units amounts to 0·768d. per unit. The load factor of the increased output has been 23·2 per cent.

The figures given on the tables need little explanation, but I would particularly call your attention to the fact that there is a difference of 293,095 k.w. between the total capacity of the plant installed and the maximum load recorded, that is to say, that no less than 37 per cent. of the total plant is provided as spare. This represents a capital expenditure of over six millions which is entirely unproductive, inasmuch as it does not earn one penny of income.

I roughly estimate that within a distance of eight or ten miles of the Manchester Town Hall there are some twenty public generating stations, having between them a total capacity of 100,000 k.w., which has probably cost over two million pounds. To construct a system of mains partly above and partly below ground so as to interconnect these generating stations would cost about £150,000, but by so doing it would be possible to reduce the quantity of spare plant from 37 per cent. to, say, 12 per cent., and enable the existing stations to supply an increase in load of 25,000 k.w. without any further expenditure, thus making use of existing plant having a value of about £500,000 at a cost of £150,000 on mains. Some additional expenditure would be necessary to provide converters at some of the existing works, but against this might be put the saving in working expenses through running the plant at higher efficiencies.

Bearing in mind the rapidity with which power stations were constructed one after the other about 1894, it may be said that with the knowledge and experience then available the majority of the work was carried out on lines that have very well withstood the test of time. On carefully considering the matter, it appears to me that only one serious mistake was made, which has only become apparent as one extension after another has had to be carried out to meet the demands of a rapidly increasing business. I refer to the somewhat common practice originally adopted of erecting the generating stations in thickly populated districts in order to keep down the expenditure on mains, without taking into consideration either the facilities provided for obtaining delivery of fuel, the provision of an adequate supply of water for condensing purposes, or providing ample room for extensions.

In the early nineties a difference of opinion existed as to the relative advantages of single acting and double acting engines; a similar problem is with us to-day in regard to the principle of turbine construction. With the small plants of, say, 250 k.w. used in the past it

would probably have been difficult to prove that any great difference existed between one type of engine and the other, although in the still larger sizes the double acting engine has been the most successful. At the present time equally good results are apparently being obtained from both the impulse and the reaction type of turbine, but if we accept as a sign of the times what is being done in other countries, it would appear that the impulse machine is being used to an increasing extent in the large sizes. The tendency of turbine construction is to increase the clearances, to reduce the number of stages, and to shorten the length between bearings, and progress along these lines is likely to be more successful with the impulse than with the reaction machine.

A question of some importance to supply undertakings is to what extent the costs can be reduced by the employment of exhaust steam turbines. Many generating stations are wholly or partly equipped with reciprocating engines, and the advisability or otherwise of installing exhaust turbines to work in connection with such plants requires consideration. In order to illustrate the effect of installing exhaust turbines in an existing generating station, I have worked out the following example :—

Application of Exhaust Steam Turbines to Reciprocating Engines in Existing Generating Stations.

Plant installed assumed to be—

6 compound sets equal to	2,000 k.w.
Two 1,000-k.w. triple sets ...	2,000 „
Total capacity	4,000 „

Steam Consumptions allowing one 1,000-k.w. set as spare.

Under condensing conditions :—

2,000 k.w.-hours at 24·0 lbs. ...	48,000 lbs.
1,000 k.w.-hours at 18·5 lbs. ...	18,500 „
3,000 k.w.-hours, average 22·2 lbs....	66,500 „

Under non-condensing conditions :—

2,000 k.w.-hours at 31·0 lbs. ...	62,000 lbs.
1,000 k.w.-hours at 24·5 lbs. ...	24,500 „
3,000 k.w.-hours, average 28·8 lbs.	86,500 „

Deducting 10 per cent. for losses, the net steam available for exhaust turbines is	77,850 lbs.
With a consumption of 37·5 lbs. per k.w.-hour, exhaust turbines will give an additional output of	2,076 k.w.-hours.

So that the working capacity of the plant becomes	5,076 k.w.-hours.
And as the steam consumption is a total of 86,500 lbs., the overall consumption of the reciprocating and exhaust turbine plant is	17·0 lbs. per k.w.-hour.

RESULT.

Increase in capacity obtained under condensing conditions	69 per cent.
Reduction in the steam consumption of prime movers	23·4 ,,

It is as well to point out that, although the reduction on steam consumption of the prime movers works out at 23·4 per cent., the actual saving in the fuel used per unit sold will be very much less, after making allowances for the constant losses in auxiliaries, condensation, and the extra power required to obtain the high vacuum; moreover, the probability is that some 70 to 80 per cent. of the total output is already being supplied by the 1,000-k.w. sets having a consumption of 18·5 lbs. per k.w.-hour, so that the saving on the steam consumption of the remainder of the output, consisting largely of peak loads, will only be a percentage of a percentage.

The cost of installing two or more sets of exhaust turbine plant having a total capacity of 2,076 k.w., together with high vacuum pumps and condensers, will be £18,000 to £21,000. The same capacity of plant, including a single unit 2,076-k.w. turbine set with its necessary complement of steam boilers, etc., could be provided for £22,000 to £25,000, and the steam consumption on one set of plant of this size would certainly be less than 17·0 lbs. per kilowatt-hour.

One of the greatest changes that has taken place in recent years has been the extended usage of multi-phase current. As this has become a common practice, it is somewhat remarkable that so little has been done in the distribution of such supply direct to consumers without conversion. A 3-phase system of generation and distribution at high, or extra high, pressure to static transformers, and thence through a 3 or 4-wire low tension network to consumers, appears to offer the highest efficiency with a minimum of cost, and, in the future, I feel sure that progress along these lines will be recorded. On the other hand, there is no doubt that many manufacturers appreciate and have taken full advantage of the improved results obtained by using direct-current motors with efficient long range speed regulating devices. For other classes of work the alternating-current motor, with the speed depending on the periodicity and practically unaffected by changes of pressure or load, has undoubtedly given good results; but except in the case of a few special trades always engaged in the production of materials of exactly the same kind, I am not altogether convinced that a direct-current motor with speed regulation will not be equally satisfactory.

It naturally follows, I think, that what may be the best speed for a given machine, be it a lathe, a rolling mill, a spinning mule or frame, or a loom, when in use on one particular class of work, will not be the best speed when in use for a different class of work, and, therefore, some range of speed is a very desirable thing to have.

The development of our public supply undertakings has been very materially assisted by the hiring-out of different kinds of apparatus, particularly of motors, and I venture to say that, had our undertakings not been in a position to carry out such work, there would have been much slower growth in power work generally than has actually been the case.

There is just one point in connection with charges for power supply on which I should like to say a few words here, in the busy industrial centre of Lancashire. When the question of power supply has been under discussion at engineering meetings in this and other districts I have heard the remark made time after time that "if any great progress is to be made in the application of motor-power supply from public mains, the price will have to be brought down to about 0·30d. per unit, because that is the total inclusive price (usually stated as rather on the high side) it is costing large consumers to work their own plant." If there is one fact more than another which stands out prominently in connection with the supply undertakings of Lancashire, it is in the tremendous growth in the demand for power supply during the last few years. At first only comparatively small users were connected, but with concessions in price the demand has increased by leaps and bounds.

In this district, where fuel can be obtained at about 8s. per ton, many large manufacturing concerns, working the usual factory hours, have found it remunerative in the long run to purchase from outside sources at a price between 0·75d. and 0·50d. per unit; but, unfortunately, it is difficult to get those who have made the change to come forward and give facts and figures to show what electrical driving has done for them. We are mostly left to assume that they are entirely satisfied through the way motor installations are extended as the opportunity occurs. There is not the slightest doubt, also, that a price between 0·75d. and 0·50d. per unit is quite sufficient to enable most of the larger undertakings to maintain and even improve their financial position. If the supply could be used 24 hours a day by a works situated near the power-station, it would be possible to quote a price of 0·20d. per unit, equal to an annual charge of £7 per kilowatt per annum. The load factor in such a case would, of course, be 100 per cent. As a better load factor than this cannot be obtained, the working expenses could not be further reduced, but a slightly lower price might still be quoted if the consumer was able to reduce appreciably, or cut out entirely, his consuming device during certain hours in the winter months, as a portion of the capital charges on the generating plant would then be allocated elsewhere.

I have endeavoured to show that progress has been made by electrical supply undertakings during the past fifteen years, and to define

some of the means whereby such progress has been possible. In this case it is, however, somewhat difficult to discriminate between the cause and the effect; but I consider that probably the most important influence has been the gradual reduction in the price of electrical plant and appliances. Large generators, which cost £6 per kilowatt, can now be obtained for £1 12s. 6d.; motors, which cost £120, can now be obtained for £30. It may, in fact, be said that the price of all standard electrical apparatus has been reduced 50 per cent. to 75 per cent. The use of electricity has in consequence steadily grown in popularity, and, with the increase in outputs, supply authorities have also been able to grant large reductions in the price per unit.

LEEDS LOCAL SECTION.

INAUGURAL ADDRESS BY THE CHAIRMAN,

W. M. ROGERSON, Member.

(*ABSTRACT.*)

(*Address delivered October* 27, 1909.)

My chief difficulty in addressing you as your chairman has been in the selection of a subject for the inaugural address. However, at a time like this perhaps it is useful and even instructive to look back to the early days of a great industry, and to compare those early days with the present. I intend to confine myself therefore to a short retrospect of those two branches of the profession with which I have been and am most intimately connected, and which in the end are really one branch, namely, the supply of electrical energy for lighting power and tramways.

ELECTRIC LIGHTING AND POWER SUPPLY.

Ten years ago 93 municipalities had established electric generating stations, having a total capital of £5,734,938, while some 70 companies were also undertakers with a total capital of £5,261,763. At the end of 1908, which is the latest date up to which the returns are available, there were 541 undertakings, 338 of which belong to local authorities, and 203 to companies or private individuals, the total capital involved being £40,016,300 and £40,722,000 respectively. The total lamps connected, equivalent to 8 c.p. ten years ago, were 4,106,727, which have now increased to 35,56,700, while the output in Board of Trade units sold both by companies and municipalities has increased in ten years from 60,125,500 to no less than 749,594,200.

No doubt the large increase in output is greatly due to the decrease in the cost of producing electrical energy, and consequently the lower rate per unit at which it can be sold. I find that taking six typical generating stations, the average cost per unit sold in pence, in 1898, was as follows: Coal, 0·46; oil, waste, wages, repairs, etc., 0·70; works' costs, 1·16; total costs, exclusive of interest and sinking fund, 1·85; while the average costs in the same generating stations to-day are as follows: Coal, 0·26; oil, waste, repairs, etc., 0·30; works costs

0·56; total costs, exclusive of interest and sinking fund, 0·78; or roughly, each B.O.T. unit sold in 1898 cost over 1¾d. to produce, while to-day the cost has come down to almost ¾d.

There are, of course, many things which account for the great reduction in the cost, the largest contributor being no doubt the advent of electric supply for power and tramway purposes, thus providing a day load for the plant laid down, and also spreading the works standing charges as well as the interest and sinking fund charges in the case of municipalities over a large number of units.

Systems of supply have not materially altered, both continuous-current and single-phase alternating being still existent. Two- and 3-phase alternating-current systems have, however, been evolved, and as by these systems supplies can be given at high pressures for power work, they will no doubt be universally adopted when new plant is installed, and more especially where large areas are to be covered.

Coming now down to the details which make up a supply station, it is interesting to trace a few of the developments that have taken place.

Machinery.

In the early days the Lancashire boiler was almost universally adopted, though the water-tube boiler of the Babcock and Wilcox type was second favourite, and to-day the Lancashire and water-tube boilers still hold the sway, with perhaps the water-tube as favourite; contrary to prophecy, it may now be taken that the useful life of a water-tube boiler will be far greater than the Lancashire or any similar type under given conditions.

As far as the boiler house is concerned, probably the most notable fact is the lower and cheaper qualities of bituminous coal that are now being burnt, and this is attributable to the great success of mechanical stokers. With hand-firing it is not practical to have a longer length of grate than 7 ft., but with mechanical arrangements grates can be made as long as 10 ft. and even 14 ft., so that with low grade and dirty fuel the evaporation posible with a high grade fuel can still be maintained.

Much more attention is also given to the critical study of the commercial value of coal by the carrying out of careful boiler tests, a common basis being the cost of evaporating 1,000 lbs. of water from and at 212° F., or the number of pounds of water evaporated from and at 212° F. per 1d. of cost.

Engine House.

First came the controversy, especially in Lancashire and Yorkshire, as to the use for prime movers of slow-speed horizontal or vertical steam engine as against the high-speed enclosed or semi-enclosed type.

A large number of stations adopting the high-tension alternating-

current system also adopted the slow-speed engine, with rope drive; while generally the low-tension continuous-current station adopted the high-speed engine, direct coupled to the generator—the reason for this was that in those days it was somewhat difficult to run alternators in parallel, while continuous-current sets could easily be so run.

With the extension of demand came the need of larger units, 100 k.w. being looked upon as quite a large machine in the early days. Horizontal slow-speed sets took up much valuable room, hence the high-speed vertical type came more and more into prominence, as well as an added demand for the slow-speed vertical type.

However, in 1884, the Hon. C. A. Parsons brought out his first steam turbine, and by 1888 an aggregate of 4,000 H.P., of turbines was at work up to 120 H.P., though none of them condensing. Since that time the size of turbine has gradually increased, until units of 5,000 k.w. are quite common, while steam consumption has been gradually reduced, until the steam turbine seems likely to outrival all forms of prime mover for central station work where large units are required and adequate condensing water is obtainable, while even in small stations the recent advent of the exhaust turbine, used in conjunction with the existing plant, may tend to bring down working costs and so promote efficiency.

The gas and oil engine may, however, prove great rivals in the field, until that which all are seeking arrives, the gas turbine.

Electric Machinery.

Little advance has been made in the efficiency of the generating plant, and indeed there was little to expect with an existing efficiency of some 90 to 93 per cent.; large units have, of course, been constructed, and the form of generator modified to keep in touch with its prime mover.

Progress in the method of construction and improved quality of material have, of course, added to the efficiency of modern machines. In high-speed machines the use of stalloy iron may increase the efficiency by 1 to 2 per cent. The use of interpoles on direct-current machines is beneficial from the efficiency point of view; the losses in the commutator can be much reduced by the use of interpoles, though the losses in the interpoles themselves have to be remembered, and as the air-gap can be much smaller than in machines without interpoles there are smaller field losses.

In transformer construction the use of stalloy iron has reduced the no-load losses by 40 to 50 per cent. without increasing the prime cost of the apparatus.

Switchgear.

Vast improvements have been made in switchgear, the work being now far more substantial necessarily owing to the use of heavy currents and higher voltages.

Considerable economies have been effected both by the use of simple devices and arrangements for the meeting of given service conditions, and also by the simplification of constructional details in individual pieces of apparatus, and the recent reduction in the cost of aluminium is bringing this material into use in place of copper, now that satisfactory methods of working it have been evolved.

STORAGE BATTERIES.

The enlightened application of electrical storage to the needs of a power station, whether direct or alternating current be generated, is proving another fruitful source of saving in operating costs. While, of course, a load which can be economically dealt with by a generator should never be thrown on storage, yet there are in every generating station fitful and fluctuating demands that are unremunerative if supplied direct, in which case storage becomes a real boon, and properly proportioned as to capacity, may be made to contribute to revenue, so that the capital expenditure on the battery equipment, plus interest, upkeep, etc., are entirely redeemed in the course of a few years.

No great changes in the construction of accumulators have to be chronicled, yet present-day cells of reputed makers are in numerous respects an important advance due to careful development and improved methods of mounting.

Negative plates of the "box type," in which the active material is no longer expected to be partly self-supporting, retain their porosity and capacity much longer than the plate form.

By thorough screening of plates of opposite polarity by porous diaphragms, the tendency to buckling has been lessened, and the avoidance of internal structures as far as possible (plates being now almost universally suspended in tension, instead of resting on bottom blocks) taken together with a liberal clearance for sediment, puts off for years the need of cleaning-out operations, and thus tends to increase the useful life of cells.

The revenue-earning capacities of a battery on the old time method of floating batteries with cell regulators is not the most profitable way of using storage, and its real potentialities can only be brought out by the automatic reversible booster. With modern practice, a quick-acting sensitive reversible booster controls the battery, and compels it to contribute its fair share of the work during the entire twenty-four hours of the day, and thus enables the boilers, engines, and generators to be operated throughout at the point of highest efficiency. Efficient control, in fact, is the crux of storage battery engineering, as on this, far more than on the battery itself, depends the success or otherwise.

MAINS.

Vulcanised rubber was largely used as an insulating material in the early days. Rubber insulation has, however, proved unsatisfactory, and to a large extent vulcanised bitumen and lead-sheathed paper cables

have taken its place. Also the type of cable has to a large extent been changed, triple concentric and three-core taking the place of three singles, so diminishing the cost of the necessary protection, and minimising the chance of electrolysis.

Another consideration has been the very greatly diminished cost of service connections, though there is no doubt room for great improvements in this direction still.

Meters.

Meters will now start on a smaller current, are accurate on much smaller loads, and give a straight curve up to full load and also with considerable overload ; starting current is indeed of great importance with the introduction of the new metallic filament lamps.

Tramways.

In 1898 only some 40 electric tramways were in existence, with a capital of approximately £24,000,000, while from the latest returns there are at present 305 undertakings in the United Kingdom, with a capital of £68,199,918, the gross receipts being £12,439,625, while the total number of passengers carried per annum amount to the large total of 2,625,532,895.

It is greatly to be regretted that such a headlong rush was made in the construction of electric tramways, as they have in the case of the smaller undertakings proved to a large extent a failure from a financial point of view. This is no doubt due to the fact that the fares charged have been fixed far too low, and that the enormous cost of upkeep was not thoroughly understood, more especially in the case of the track.

The principal improvements which have taken place in tramway apparatus during the last few years refer to mechanical detail and workmanship, and have resulted in increased reliability, freedom from breakdown, and improved facilities for inspection and repair. Motors instead of having cast-iron fields have the fields now of steel ; workmanship has been greatly improved, and motor parts are now made interchangeable.

Other improvements have been made, such as rigidly fixing the brush holders, while the housings for the armature bearings are now fixed to the top half of the motor, thus permitting the lower half to be dropped, the armature remaining suspended in the upper half.

The use of laminated poles in place of cast-iron poles has enabled the pole spacing to be made much more accurately, with consequent improvement of commutation, and with motors of large size, commutating poles are now coming into extensive use; but with smaller motors, where the commutating conditions are naturally good, and where there is little trouble from flash-overs, it is questionable whether the addition of commutating poles, with their extra cost and complication, is warranted. With controllers, the introduction of mica in the

construction of the drums is an advance, as is also the method of providing the fingers with renewable tips, cutting down the cost in this direction very considerably. The up-to-date controller consists of a smaller number of complete standardised sections, so assisting greatly in its prompt repair, with lessened cost of upkeep.

Power resistances are now almost invariably made of cast grids, which are cheap, reliable, and easily renewable and adjustable to suit the requirements of traffic, gradients, etc.; these also replace the earlier form of spiral resistances of steel, or German silver strips wound in cells.

In conclusion, I do not intend to speculate on the future. There will still be trouble to face and worlds to conquer ten years hence, and we shall still have to put in our best energies to the work in hand.

I thank you for your patience in listening to these notes, and I trust that much benefit will be derived from our meetings during the current year, and that future presidents will have the same satisfaction as I have in fulfilling this important position.

BIRMINGHAM LOCAL SECTION.

INAUGURAL ADDRESS BY THE CHAIRMAN,

R. K. MORCOM, Member.

(*ABSTRACT.*)

(*Address delivered November* 3, 1909.)

I have to thank you for the honour you do me in choosing me as your Chairman for the coming session. There appears to be no doubt that at present the electrical industry is passing through difficult times. There is a great deal of severe competition both home and foreign, and the market itself is not expanding as satisfactorily as in the past. More particularly I wish to consider the state of the primary branch of the industry—namely, large electrical engineering—which will be referred to as "the industry" in many places.

In some respects the state of the electrical industry is difficult to analyse. Its development depends upon the development of a practically new science, and its progress is affected not only by the general progress of trade, but also by the success of its competition with older methods of attaining particular ends.

In studying the period from 1900 to the present day from available statistics, it at once becomes apparent that immediately the disturbance caused by the South African War had subsided, the trend of trade was upwards on a very steep curve, except that 1904 and 1908 were noticeably periods of depression. So far as the Board of Trade returns for total imports and exports are concerned, the 1904 depression is masked by the demands of the Russo-Japanese War, whereas that of 1908 is obvious. To find the signs of the former depression we must go to other figures. Among the chief users of electrical power are the textile, the iron and steel, engineering, shipbuilding, chemical, and mining industries. A study of the Board of Trade returns for these industries reveals the signs of depression not in the textile industry, which shows a steady increase up to 1907, but in the others. In the iron and steel industry there was a decided falling off in exports during 1904. The chemical exports instead of increasing were almost steady, the machinery exports showed an increase less than that shown in either 1903 or 1905. Also there was a falling off in shipbuilding in

1903–4 for vessels for our mercantile marine. There was likewise a fall in the rates of increase of coal and pig-iron production.

The depression of 1908 is much more marked, and statistics show a retrograde movement all round—a very serious one in the textile trade, and actual decreases in all the other above-mentioned industries. As further indicating that these were years of depression, the returns of unemployment show a peak in both.

Another important consideration bearing on the progress of the industry is to be found in the expansion of public supply. There was an increase from 1906 to 1907 of 179 million units, the increase from 1907 to 1908 was only 104 million units. The increases of plant installed for supply undertakings have likewise fallen off considerably in the last year or two.

The traction figures for municipal trams extended but slowly during 1908. The expenditure of tramway companies was very considerable, but Mr. Garcke points out that the rate of growth of increase is not maintained, and a considerable portion was accounted for by railway companies' electrical expenditure. The Board of Trade returns treating of the electrical industry itself are incomplete and unsatisfactory. Roughly they reveal that whereas our imports of electrical machinery have since 1903 maintained a fairly constant level of, say, £600,000, our exports have risen from just under half a million to about one and one-third million. Figures of electrical exports and imports, excluding machinery, have been subject to various adjustments and classifications which obscure them, but the position may be summed up by saying that the imports have shown an almost steady rise, while exports fell severely in 1904 and again in 1908. The exact value of our home market for electrical machinery is one that is difficult to estimate. The census of production figures for the industry are not available, and unlike some of our foreign competitors, we do not seem anxious to publish particulars of our sales. Occasionally some indication is offered in prospectuses, but incomplete and sometimes over-optimistic. I endeavoured to get at it in a roundabout way as follows: I obtained, after considerable inquiry, particulars of the number of employees of leading firms. I also got from some of them the proportion existing between the export and home trade in a sufficient number of cases to suggest an average figure. The average was taken, the percentage from each firm being properly weighted by multiplying it by the number of employees. As the figures given were confidential I can only give my results as follows: This rate for 1908 works out at 31½ per cent. foreign and 68½ per cent. home. The figures are necessarily approximate only, but indicate that our home consumption is in the neighbourhood of £3,000,000, our exports one and one-third million, and imports half a million. In comparison with previous years our exports appear to have increased faster than the home consumption.

Another noticeable point has been the falling off in the ratio, in our home consumption, between work for public service to that for

private service. A recent estimate of the municipal demand was about 1½ million per annum. To-day's figure is probably a good bit less than this.

So far the analysis has been chiefly confined to the consideration of the market for finished goods. The prices of raw materials will next be taken. The most noticeable feature of the century was the rise in price of copper in 1906–7 to a value double that prevailing in 1894–5. This rise, it will be seen, occurred on a falling market for electrical machinery, and was a factor in producing considerable distress to manufacturing concerns. The average price of imported puddled and pig iron from a very low figure in 1901 has risen steadily till in 1908 it was nearly 60 per cent. above the former figure. The export prices were more steady, the variation from the minimum to a maximum in 1907 was, however, about 40 per cent. The average market price for Cleveland pig iron has been high throughout the whole period; it was abnormally high in 1900, and also reached a maximum in 1907 at 30 per cent. above the minimum for the period. Under these conditions of output and prices of raw materials what has been the progress of selling prices? As an indication I propose to take instances which represent the general trend, selecting the branch for which the figures are most easily accessible to me—namely, generating sets for coupling to high-speed engines. I propose to give the price per kilowatt of alternating- and direct-current machines of about 250 k.w. and about 1,000 k.w. The averages thus obtained for 1901–2 were £3·6, £3·4, £2·6, £3·0 per kilowatt. These started at once to fall, first slowly, then rapidly in 1904, and then again gradually, till to-day the corresponding figures are £1·9, £1·85, £1·5, £1·55. The trend of prices has been similar in practically all branches of the trade, and in the allied industries of stationary engine building and steam turbine building. The increased price of raw materials in 1906–7 made no difference to the rate of fall.

A further point that needs consideration is the distribution of capital in the industry. The figures for this capitalisation are given in Garcke's Manual, but unfortunately they are very disguised by the inclusion of a large number of companies whose staple product is not electrical, or who are merely agents for foreign manufacturers. I have attempted a closer analysis of the figures for the three years 1896, 1902, and 1908, which I tabulate as follows:—

Year.	Large Engineering.	Cables.	Lamps, Fitting, and Wiring.	Traction Accessories.	Instruments and Accumulators.	Foreign Agencies.
1896	1,700,000	1,400,000	880,000	—	450,000	130,000
1902	5,000,000	2,500,000	2,200,000	600,000	900,000	500,000
1908	9,000,000	3,200,000	4,300,000	500,000	1,400,000	500,000

The heavy capitalisation in the engineering section is one particularly worth note, and its effect may be usefully illustrated by a wider review than has been hitherto adopted.

In a way it is a young industry, but past its infancy. In its infancy it suffered from one very bad slump in the early and middle 80's, similar to that which recently hit the infant motor-car industry. This slump was undoubtedly due to the great rush of capital into an industry, based on a mistaken idea as to its immediate future. In the year 1882 alone nearly £9,000,000 of capital was raised for electrical enterprises. As a result competition was so keen as to reduce profits to vanishing-point. Improved methods of manufacture and gradual realisation of the over-eager anticipations of the companies gradually steadied the industry into one of increasing prosperity.

The progress of electric lighting, which came with the improved design and cheapness of lamps, continued steadily. Electric traction found more and more application, and up-to-date manufacturers, by adopting electric drive because of its convenience, cleanliness, and economy, all brought grist to the mill, and a remunerative business was done during the closing years of the last century by a number of concerns whose names are household words with us.

The beginning of the twentieth century seems to have heralded harder times. The older companies, led on by their excellent trade, increased their capital, and new enterprise was tempted in by the evident prosperity of the business, till to-day we are again in the position that if all our works were full, the demands of our home and export trade would not be enough to take their output.

It is certain that had it not been for increased productivity, the first seven years of this century, excepting 1904, would have been progressively profitable. In fact, 1906–7 were remarkably good years. The introduction of the metallic filament lamp has undoubtedly reduced the requirements in machinery, and it remains for the increased cheapness and efficiency of electric light to stimulate the demand to a pitch when plant requirements shall again assume an upward grade. Cheap electrical power is encouraging further industrial application, and if experience of heavy traction, at present on its trial, is satisfactory, it is only a matter of time before this application is extended. Tramway work is bound to extend with increasing urban population.

In shipbuilding more and more work is being done electrically, and the electrical requirements of the ships are growing, while at present the air is full of rumours of the close approach of electro marine propulsion. All these things give hope that, as the capitalisation which caused the slump in the early 80's was justified in the 90's, that of the first decade of this century may be justified in the second.

But to cause such a demand capital and enterprise are required. I use the word capital in the usually understood sense of capital in bulk. Without free capital we must look to great restriction of our home market which is at present our chief one, with the likeli-

hood of foreign competition such as occurred in 1904. The other great markets of the world are practically closed to us. Our Colonial industries though growing rapidly are not yet large enough to make up the deficit, and the same may be said of various non-manufacturing countries. The industry is so large and important that in foreign countries it receives special support from their Governments, and it is estimated that in Germany the number of employees increased from 1904 to 1906 from 72,500 to 95,000. According to Garcke, the comparative British figures for 1907 would be 45,000. It is estimated that the whole of the electrical industry in this country employs 300,000 persons, so that its prosperity may seriously affect the question of unemployment. In the large engineering branch capital must play a great part. Contracts are severe, and payments for the finished article are often held up for long periods. All the while the wages of labour must be promptly and fully paid. Capital is the flywheel of industry, which keeps things going steadily under the fluctuating impulses of demand, and enables the machinery to grind out at an even rate the current of wages. I find from figures of numbers of employees, and of the capital of a number of our leading companies that on the average £300 of capital must be found to provide workshop, tools, security, and trade for every single workman.

The average capital expended on buildings and plant is nearly £200 per man employed. The staff expenses for technical and clerical work are necessarily very high, many instances equalling the wages bill; while, taking an average for the clerical staff of a number of the large firms, it will be found that one clerk is required for every three to four workmen. In this connection the annual report of the American G.E.C. is most interesting. From the 1907 report I glean the following: Area, 4,770,000 sq. ft.; employees, 28,000; cost, $1·12 per square foot; orders, $60,000,000; capital, $64,000,000.

To give plenty of business and full employment to our engineers and factories, not only must our 1910 goods be better than our previous ones, they must be better than any one else's 1910 goods, and this is largely in the hands of our technical schools and teachers.

A noticeable feature in the addresses of Chairmen of Local Sections of late years has been the stress laid on the education problem, and very rightly.

That a man in his time must play many parts has never applied to any one, I think, as much as to the modern engineer. It has been pointed out that he may have to be a physicist, mechanic, accountant, salesman, organiser of labour, and judge, and you cannot be educated to all that. All that our teachers can do is to lay the right foundation of knowledge and leave experience to do the rest. So much has been said and written by able men on this point that I can but refer you to their writings and words for guidance in forming your own opinions, but there is one point on which I feel strongly, and that is that there is rather a tendency to discourage pure in favour of applied science. The value of mathematics, in particular as a training, should never

be overlooked. Given zeal, I believe that mathematics, and plenty of it, will take a man further than any other training. It will give him that most valuable commodity, a well-ordered mind. A common experience is that if a student experienced difficulty in, say, advanced arithmetic, he would go back to it as child's play after a bout with algebra, and when algebra begins to get vague a dose of differential will send him back to scoff at the former difficulty, and so on into higher fields. A sound mathematician can always more readily specialise on a physical subject than another man—he is trained to reason.

Too many engineering text-books are now written which make a boast of their non-mathematical nature. It certainly makes the book fatter and more expensive, but mathematics are labour-saving appliances, and should be used. Those who cannot use them should take the results they produce for granted, like a labourer with a complicated automatic.

Take a mathematician, give him a workshop training, and let him read the technical papers instead of the sporting columns of the daily press, and he will make an engineer. If he also has the gift of common sense and zeal for his profession he will make a good engineer. An engineer whose knowledge of mathematics and pure science is rudimentary is to his truly educated *confrère* much what a pianola player is to a pianist.

DUBLIN LOCAL SECTION.

INAUGURAL ADDRESS BY THE CHAIRMAN,

Professor W. BROWN, B.Sc., Member.

(*ABSTRACT.*)

(*Address delivered November* 11, 1909.)

I dare say the majority of the members of this Local Section have been for years so actively engaged with the commercial side of their profession that they have scarcely had time to keep in touch with the developments that have taken place in the magnetic testing of iron since their own college days, and therefore a short address on this subject may be of interest.

I make no apology for taking iron as my text, because it is of the greatest interest to all electrical engineers, and the testing of iron magnetically has long passed the experimental or laboratory stage, and is an operation of the utmost practical importance in the building of dynamos, transformers, etc. I propose therefore, as far as time permits, to take a historical and critical review of the various methods of testing iron, and to touch on the more important steps taken in the development of the subject during the last forty years.

The first extensive and accurate experiments on the magnetic permeability of iron in absolute measure were made in 1870 by Rowland, who was the first to show experimentally that the permeability of iron was not constant, but was a function of the *magnetism.* He also first expressed his results in our modern language of "lines of magnetic force." Rowland used the "ballistic method" of experiment, the samples of iron being in the form of a closed iron ring, which had a magnetising coil and an exploring coil wound over it.

This ballistic method of testing is no doubt the most accurate when we wish to investigate the magnetic properties of iron from a strictly scientific point of view, more than from the point of view of its commercial application. But the experiment is long and tedious, on account of the magnetising coil and ballistic coil both having to be wound on each specimen, and even when the observations have all been made a good deal of time is consumed in performing the

calculations, not to speak of the time and care required to standardise the ballistic galvanometer.

The next step taken in the work (in 1882) was by R. Shida, in the Glasgow University, who made some determinations of the magnetic susceptibility of iron in absolute C.G.S. measure. He used a magnetometric method of experiment—subsequently employed and improved by Ewing—in which both the magnetising coil and the specimen of iron under test could be moved up or down vertically in a line at a fixed distance from the magnetometer, and thus he was able to measure the distribution of magnetism along the specimen. This method of testing iron adopted by Shida is much more laborious and tedious than we should think of adopting nowadays, but as a method suggested at the time by Sir W. Thomson (Lord Kelvin), it has at least a historic interest.

We next come to the all-important work of Ewing, who may be regarded as the best authority on iron testing. He read his now classical paper on the subject before the Royal Society, London, in 1885; in his work he used both the ballistic and magnetometric methods of experiment. The magnetometric method used by Ewing is more straightforward, and is as accurate as the ballistic ring method if the specimens of iron under test are rods at least 400 diameters long, a condition which Ewing proved experimentally. Both these methods are more laboratory than workshop tests; but still, in my opinion, the magnetometric method is the most convenient when we want accurate results in a comparatively short time.

A few months after Ewing's paper was read a very important communication was given to the same Society on this subject by Dr. J. Hopkinson, who was the first to give the chemical composition of the specimens he tested, and to emphasise its importance. The method of test he adopted is that now known as the bar and yoke or divided bar method, which is really a modified form of the ring method, though not so good on account of the number of joints in the magnetic circuit. In Hopkinson's method the time taken to prepare the specimens is a consideration, and more important still is the difficulty of getting good iron to iron contact where the parts of the bar come together. It was, however, a distinct advance, from a practical or workshop point of view, on the previous laboratory methods in use.

Next came Ewing's hysteresis tester, in which, though some time also is required to prepare the specimens, we have a handy workshop instrument, and though it determines the value of the magnetic induction for a few points only on the curve, it is sufficient to indicate if the specimen is near or within the limits specified by the manufacturer. This is itself an important consideration, as it may often save time which would be consumed in a longer test. Ewing's bridge also requires time to prepare the specimens for a test. It is a modified form of the ring method, with the air-gap effects fairly well got over, and a magnetic balance is obtained against a standard rod instead of

finding the absolute value. As a workshop, or even a laboratory instrument, it is valuable for getting the first up-going or permeability part of the curve, and with it calculation is reduced to a minimum.

We next come to the permeameter of Professor S. P. Thompson, which has the objection of all traction methods—namely, the presence more or less of air-gaps in the magnetic circuit, as well as the old difficulty of getting good iron-to-iron contact. Air-gaps, even of the smallest, as is well known, have a great influence on the magnetic flux. The instrument has its merits as a workshop tool, and is useful in a laboratory.

Of the magnetic balance type of tester, du Bois' form makes use of an air-gap, and measures the attraction, or pull, of the magnetised specimen across it; whereas in Ewing's balance the air-gap is practically got rid of and the iron-to-iron contact reduced to a mere line. One great advantage of these magnetic balances is that one can get the result either by multiplying by a simple number or by reading off direct; the constants have been previously obtained by means of standard rods.

In the μ-meter of Messrs. Lamb and Walker we have quite a new departure, where an air-gap is actually made the standard of reference, that is, the magnetic reluctance of something unknown (the iron) is balanced against, or compared with, the reluctance of the air-gap, which is quite definite and is unity. I will now determine a couple of points for the rod in the instrument before you, and you will see what a small change in the length of the air-gap upsets the magnetic balance. This instrument is so compact and so easily manipulated that I am surprised it has not been more used. I think that it gives us a very distinct advance in the methods of testing iron, even though some little time is taken up in preparing the sample for test. Drysdale's permeameter, which is for testing iron in bulk, is essentially a workshop instrument. I think that the testing of a small part of a bulky material is very doubtful; the assumption is made that the material is homogeneous throughout, but the result of a test at one part might not agree with that made at another part. The small iron pin—the part really tested—may be changed physically in the process of drilling, and there must be small air-gaps between the pin and conical plug and between the plug and mass of material, all of which, one would think, would affect the results. Drysdale, however, says that the results got with this instrument are within 2 or 3 per cent. of those obtained with the same material by the ring ballistic method, so that, on the whole, we may say that the instrument is a suitable workshop tool.

The methods of Professors Fleming and Beattie for testing the hysteresis loss in iron by means of alternating currents are of extreme interest, and are of great use when once the apparatus has been set up and calibrated. I have only been able to give a sketch of these methods, for to discuss them as they deserve would open up a very wide field, and would lead far beyond the time limits of the present address.

GLASGOW LOCAL SECTION.

INAUGURAL ADDRESS BY THE CHAIRMAN,

E. GEORGE TIDD, Member.

(*ABSTRACT.*)

(*Address delivered November* 16, 1909.)

It is now twenty-five years since I joined this Institution, and in looking round for a subject on which to address you, it struck me that since I became a member, electrical science has come to the front in an extraordinary manner, and that a cursory glance at the progress made during this period by the various branches of electrical engineering might not be uninteresting.

It is difficult to divide up my subject satisfactorily, but I will make an attempt to do so by dealing with the following points in sequence as named :—

Our own Institution.
Telegraphs and Telephones.
Electric Supply.
Traction.
Manufacturing.
Installation and Wiring.
Application to various Industries.

This Institution was established in 1871 as "The Society of Telegraph Engineers." Ten years later an addition was made to its name, and the title altered to "The Society of Telegraph Engineers and Electricians." This somewhat widened the scope of the Society, and permitted the admission of the growing body of men who were employing themselves in electrical work outside the work which had hitherto been confined to the working of telegraphs. This body increased at such a rapid rate that the new name very quickly became a misnomer and misleading, and in November, 1883, it was changed to its present form, "The Institution of Electrical Engineers."

In dealing with the Institution, one must, of course, refer to the introduction of Local Sections. In 1899 the Council realised that the members of the Institution were so widely spread over the kingdom as to be unable to take advantage of the meetings held in London, and

were therefore liable to get out of touch with it, and they saw that a tendency was springing up to establish local institutions, having similar aims. They decided that it would be advantageous to link the members residing in the chief districts of the kingdom more closely with the parent Institution.

All engineers are willing to recognise the high standing of the doyen of all institutions, viz., the Institution of Civil Engineers, and this Institution does so with perfect complacency, for, though the Institution of Civil Engineers dates back very much further than our Institution, when we consider the rapid strides made by ourselves within recent years, we may hope in time to be equally powerful, and as conducive to the well-being of the profession as the older body.

I may mention that in 1886 the membership of the then Society of Telegraph Engineers and Electricians was 1,330 of all ranks. A year after the change of name it had increased to 1,491, and this year the returns show a total membership of all classes of 6,117.

One cannot leave our Institution without a reference to, perhaps, the most important step in its history, viz., the possession of a home of its own. It made various moves in the neighbourhood of Westminster, and on each occasion to larger and more suitable premises, but despite the increased accommodation, it had to be beholden to other institutions for facilities for the reading and discussion of papers. To get rid of this difficulty, the Council have recently completed the purchase of what was formerly known as the "Medical Examination Hall," on the Thames Embankment. Any who have seen this building will realise that it is a home which for a very long term will be in every way worthy its purposes.

In reviewing the electrical progress during the last quarter of a century, the most obvious section to commence with is that of telegraphy.

We may give a casual glance at the earlier stages. As is well known, the first practical telegraph was laid down in 1837, while the first commercial company for undertaking the business was incorporated in 1846. It was not, however, until 1870 that the State took over the business of the thirty odd companies which were then carrying out telegraphic work in the kingdom. In 1884–5 the total number of messages passed over the Government telegraph lines was 33,278,459. This was accomplished at an expenditure of £1,820,764. Twelve years later, the number of messages had increased to 74,423,556, involving an expenditure of £3,108,067, while last year the total number of messages had reached 85,969,000, and the expenditure was £5,335,996.

In reviewing the telegraphic enterprise, one cannot pass over the submarine cable work, which is entirely in the hands of companies. Twenty-five years ago Lord Kelvin's work in this connection was beginning to become a matter of history, and a considerable number of cables had been laid, but the volume of cablegrams was not extraordinary.

In 1896 there were twenty-three undertakings, having a total capital

of £31,103,254, while in the present year the total number of undertakings has risen to thirty-four, involving a total capital of £36,283,038.

About the first to be heard of wireless telegraphy was when Mr. (now Sir) William Preece set up a system of telegraphic communication without direct-connecting wires, but really the first utilitarian system was that brought forward in 1895 by Signor Marconi.

The Telephone was patented in 1876, and four years later the Bell and Edison Companies amalgamated as the United Telephone Company, and started operations. After the Company had been working for a few years, the Postmaster-General took action against it for infringement of monopoly, and obtained judgment to the effect that the Telephone is a Telegraph within the meaning of the Telegraphs Act. The following year, however, 1881, the first licence was granted by the Post Office to the United Telephone Company, enabling it to conduct operations within 5 miles of the Town Hall.

In 1889 the amalgamation took place between the United Telephone Company and some of the subsidiary companies, the amalgamated companies taking the name of the National Telephone Company, Ltd. This company has since absorbed most of the companies holding Post Office licences, and is, apart from the Post Office and certain municipal undertakings, the only company carrying out telephonic operations on a large scale in the United Kingdom.

A crisis occurred in the Telephone enterprise of the kingdom in 1892, when a select Parliamentary Committee reported in favour of the acquisition of all trunk lines, and suggested that the licence of the National Telephone Company should not be extended beyond the limit of 1911. In 1896 there were altogether eleven separate undertakings working in the United Kingdom, having a capital of £6,482,979, while last year the number of undertakings had increased to nineteen, having a total capital of £22,132,641.

In 1896 the purchase value of the trunk lines was £459,114 with 29,000 miles of wire. By 1897–8 the capital involved in trunk lines had increased to £1,185,518, in 1905 to £2,897,593, and last year the returns show a total capital outlay of £3,946,658. In 1897–8 the mileage had increased to 55,721, and the total number of trunk messages was returned at 11,776,494. In 1905 the mileage of trunk lines had increased to 128,000 and the messages to 30,923,644, while this year the mileage of trunk lines is returned at 159,353, and the trunk messages at 43,986,226.

Turning now to the question of electric supply, this may be said to date from the beginning of the period under review.

The first suggestion of electric supply was when the Select Committee of the House of Commons was appointed in 1879 to consider whether municipal corporations should be permitted to adopt electric lighting schemes. The Paris Exhibition of 1881, followed by the Electrical Exhibition at the Crystal Palace in 1882, combined with the many improvements in electrical machinery and lamps which took place about this time, stimulated considerable enthusiasm in the

subject. In 1882 the Government Bill conferring and limiting the powers to undertakers for supplying electricity received the Royal assent, and immediately several private bills were presented to Parliament by companies seeking powers to supply electricity. This Act, however, owing to the very onerous conditions which were laid down, is looked upon in most quarters as one of the greatest hindrances to electric supply. The effect of these conditions was not at first realised, and in 1883 there were no fewer than 69 Provisional Orders granted. Sixty-two of these have since been revoked, and there are only 7 of them still in force. The unfair conditions of the Act were soon realised. In 1884 a systematic movement was made by the promoters of electrical undertakings to get the 1882 Act modified, and this resulted in the passing of the 1888 Act. It is this Act which now governs supply undertakings, and its conditions are vastly less onerous than those of previous ones. The passing of the Act of 1888 gave a new impetus to the establishment of electricity undertakings, and between 1888 and 1896, 103 provisional orders were granted to companies, and 159 to municipal authorities.

The total capital expenditure in the year 1896 by municipalities and companies reached a total of £7,798,073, with a lamp connection of 2,031,398, while in 1908 the total capital expenditure had reached £87,510,348, and the lamp connection 43,798,760, and the number of B.T. units sold in the same period increased from 30 millions to 954 millions.

I think I am correct in stating that there was no public supply of electrical energy whatever available thirty years ago.

The traction aspect of electrical science can perhaps be most conveniently considered under three heads :—

TRAMWAYS.
RAILWAYS.
SELF-PROPELLED VEHICLES.

As regards Tramways, at first glance they might appear to constitute the connecting link between the other two sub-divisions, but closer investigation shows that Tramways must be admitted to have been the means of rendering commercial electric traction a possibility.

At the time when our review begins, this branch of electrical enterprise had made no start at all, and for a good many years during the past quarter of a century it made comparatively little progress in this country, notwithstanding the fact that where electric power was adopted, superiority and economy over other forms of traction were very clearly demonstrated.

In 1896 there were only 47¾ miles of track in use in the kingdom. This, of course, was a very poor show compared to the 12,000 miles which were running at this period in the United States.

In 1897 there were nine lines in course of construction or conversion for the use of electric traction, in addition to which, in that year fifteen Acts and thirteen Provisional Orders were granted for the construction

of lines. The standard system now is the overhead trolley. That it will be superseded, there is little doubt, I suppose, but whether it will be in the near or distant future is for the future to show. The capital invested at present in electric tramway systems throughout the kingdom amounts to £68,199,918.

Passing on now to the question of Railways, the first railway in the kingdom to be driven electrically was the City and South London. This, however, was one of the now well-known "Tube" Railways. The City and South London was opened in 1890. In 1893 the Liverpool Overhead Railway was opened, and for several years these two lines represented the progress made in this country towards the "supersession of the steam by the electric locomotive," as the transition was called by one of our past presidents, the late Mr. W. E. Langdon, who read to us a valuable paper on the subject. At the time that paper was presented to the Institution, the practicability of electric traction on a large scale was certainly recognised, but its commercial probability on an extended scale was undoubtedly looked upon by the majority of engineers as a chimera of the scientist. However, although perhaps no direct result can be traced to Mr. Langdon's paper, I feel convinced that it undoubtedly gave a great stimulus to the question, as it was realised that such a thoroughly practical man would not put forward a scheme which was outside the sphere of practical realisation. It was not, however, till quite recently that the big forward movement took place by the opening for traffic, after the entire conversion to electric traction, of 82 miles of the Southport line of the Lancashire and Yorkshire Railway in 1904; of 83 miles of the Tyneside line of the North-Eastern Railway in 1904; and of over 200 miles of the Metropolitan and District Railway in London in 1905.

Turning now to the state of the manufacturing business in 1885, at that time manufacturers were just beginning to shake off the ideas of the telegraph engineer. Most of the firms of that period were the outcome of the businesses which had been started for the construction of the lighter class of electrical goods and electrical instruments, and, from the mechanical engineer's standpoint, many of them were very deficient. Possibly one of the greatest features which has assisted the manufacturers to arrive at the present state of perfection was the introduction, by mechanical engineers, of electrical departments. This woke up the manufacturers of electrical machinery to the fact that sound mechanical engineering was the foundation of all good electrical machinery. To-day the standardisation and perfection of design in electrical machinery is probably in advance of any other class of engineering.

A branch of electrical work, which, especially to us in Glasgow, has particular interest, is the installation of electricity on board ship. The application of electricity, so far as electric lighting was concerned, was earlier recognised for this purpose than for almost any other work. The reasons are not far to seek.

On land, if it were a question of electric light superseding gas (or,

if for country mansion work, probably oil lamps), then it meant an installation of machinery, and the care and upkeep of the same; whereas on board ship there was the technical engineering staff and the available steam, and an additional engine did not appeal to shipowners as a very heavy undertaking; so that, as I have said, some of the earliest complete installations of electric light were to be found on board ship. Even in the early eighties there were a number of ships so equipped. One of the very earliest was, I believe, the Cunard steamship *Servia*, which was fitted in 1881, and on which there was installed 117 "Swan" lamps and 2 arc lamps, totalling up to about 13½ H.P. Perhaps the progress of ship lighting in general cannot be better exemplified than by making the Cunard Line a concrete example. Following the *Servia*, the next step may be looked upon as typified in the *Umbria* and *Etruria*, fitted in 1884. On these vessels there were 3 dynamos, each having a capacity 350 amperes by 100 volts; say, a total of about 140 H.P.

The *Campania* and *Lucania*, built in 1893, mark the next step in the growth of the Cunard Line vessels. The plant consisted of four Belliss-Siemens direct-coupled plants of about 70 H.P. each; there were 1,350 16-c.p. lamps fitted on board, and one 16-in. projector of 50 amperes. Besides the lighting, however, the electric plant was called upon to supply a little motive power, as there was a motor fitted in the barber's shop to drive the hair-brushing machine.

From these boats we may pass on to the present time to the *Lusitania* and *Mauretania*. In each of these vessels the plant consists of 4 generators, of a total of about 2,200 H.P., while the actual power required for all the motors and lights, if running at one time, would amount to 2,773 H.P. There are over 6,300 lamps distributed throughout the ship, and, independent of the power required for lighting, a total of 2,133 H.P. There are 166 motors of various powers, and some 30 H.P. provided for use in the kitchen for hot-plates, etc., and 106 electric radiators, absorbing about 80 H.P., which are used in special state-rooms, etc. Electric power is used for deck winches, passenger hoists, etc., besides false draught and ventilation throughout the ship.

So much for the mercantile marine. If, however, electricity has made important advances therein, the advances made in the British Navy have been equally great. Twenty-five years ago dynamos were only just beginning to be introduced into the Navy, and then solely for lighting purposes. Sixteen years ago, electricity was firmly established as the illuminating agent, and first-class battleships were fitted with 3 dynamos of a collective output of 96 k.w., there being about 700 incandescent lamps in use. At the present day first-class battleships of H.M. Navy are being fitted with generators of a collective power of 600 k.w. The number of incandescent lamps has increased to about 2,000; the size of the searchlights has been doubled, and where beforetime there was no application of electrical energy to power puposes, there are motors of an aggregate of well over 1,000 H.P. Among the purposes to which it is applied may be

mentioned ship and engine-room ventilation, coaling winches, boat hoists, capstans, pumping and refrigerating machinery, air compressors, ammunition hoists, passenger lifts, workshop machine-tool driving, motor-generators for the reduction of the pressure (220 volts) to suit the operation of the searchlights, and also of supplying low-pressure current for telephones, etc.

Within the period I have reviewed, electricity has affected almost every sphere of daily life, not only in the workshop, but also in the home as well as in ordinary business and commercial circles. In the latter it would be difficult nowadays to conceive a modern business conducted without the use of the telegraph and telephone, and for domestic and home use, while perhaps the advance is not so great in the purely domestic sphere, such as cooking and even lighting, and is perhaps not so universal and necessary yet, as doubtless it will be in the future, still the greater facilities in both these respects, apart from the contingent facilities of rapid transit, have had an undoubted effect on domestic life generally, and possibly have been factors in depopulating the cities to the advantages of the suburbs.

With regard to the commercial processes, in numbers of cases these have been entirely revolutionised by means of electricity. Electrical driving is, as we all know, now superseding every other method of driving, but apart from this, some processes, such as smelting and some chemical processes, owe their possibilities entirely to various applications of electricity.

In every department of the scientific application of electricity to everyday uses the increase of capital invested during the past twelve or thirteen years has been extraordinary; in some of them phenomenal. For instance, in 1896 manufacturing found employment for 6½ millions; in 1909 it was 42½ millions. Supply in 1896, 8 millions; in 1909, 87 millions. Traction in 1896, 6 millions; in 1909, 185 millions. The total capital invested in 1896 in electrical enterprise was 61 millions of pounds, while this year it is 386 millions. I question if any industry has ever had such an extraordinary rise. Every day finds the imponderable power being harnessed to something new. Nothing seems to be beyond the range of its possibilities. What we only dreamt of 25 years ago to-day seems commonplace. Who can say what the next 25 years will bring about? I have dealt with a number of its present-day features in but a sketchy manner, but any of them might well furnish the base for a whole paper. I may have dealt too largely with some points; too scantily with others; nay, some important features have been omitted, but what else can I do? The subject is so vast! Can I advise you to generalise or specialise? I cannot! but let each man do what in his power lies, by theory and by practical demonstration, to probe still deeper into the possibilities of this mighty force so that the world may be helped another step onward in the solution of those secrets which Nature so jealously guards, but which, when discovered, she parts with so freely.

NEWCASTLE-ON-TYNE LOCAL SECTION.

INAUGURAL ADDRESS BY THE CHAIRMAN,

Professor H. STROUD, D.Sc., Member.

(*ABSTRACT.*)

(*Address delivered November* 22, 1909.)

I desire to thank the members of the Section for the honour they have done me in electing me chairman for the ensuing year. As we have recently established a wireless telegraphy station in connection with the Physical Department of Armstrong College, it seems appropriate that I should devote my address to the subject of Radiotelegraphy, with an account of the College station.

Great progress during the last few years has been made in the production of persistent or undamped waves, in connection with which the Poulsen arc method is most prominent. These undamped waves permit great precision in tuning. They can also have their intensity altered by means of the voice acting on a suitable microphone, and thus, using a receiver which is quantitative in action and dependent on the amplitude of the waves, it is possible to transmit speech, and the foundation has been laid for the development of radiotelephony.

Further, the spark sender has been much improved, due to the introduction of the "shock excitation" system based on Wien's "quenched spark," 1906. This system is employed by the Telefunken Company, and has given excellent results.

The radiotelegraphic station in the Physical Department of Armstrong College is licensed by the Postmaster-General as one for experimental purposes. Mr. Morris-Airey has been associated with me in connection with the station, and I have much pleasure in acknowledging the enthusiasm he has exhibited in the design and equipment of the station. We have benefited by the valuable technical advice kindly given by Mr. Sörensen, engineer and manager of the Cullercoats Radiotelegraphic Station.

The towers of the College afforded a very simple method for the erection of the antenna. In its construction about 1,500 ft. of wire

cable are used; the cable is seven-stranded, and is made up of No. 20 S.W.G. bare silicium bronze wire. A double cable of this wire, about 170 ft. long between the insulators, is stretched between the Sir Lowthian Bell tower (130 ft. high) and the Jubilee Exhibition tower (80 ft. high). The double cable is insulated at each end by three porcelain insulators of special construction so as to prevent the ends of the wire falling in case of the breakage of the insulators. Two sets of cables of the same wire are attached to the 170 ft. of insulated double cable, and lead to the room where the signals are sent and received—one set consists of five cables suitably spaced towards the higher tower end, the other set consists of three cables suitably spaced towards the lower tower end. The King's Hall necessitated this division into two sets, but it is arranged by separately insulating the two sets, that the antenna can be used as a "loop" antenna, or all the eight cables can be joined at their lower ends, thus forming a "fan" antenna, but of unsymmetrical type. The connections between the insulated antenna and the experimental room are made through two leading-in tubes of porcelain above one window; each porcelain tube, which is filled with paraffin, has a brass tube, furnished with terminals at the ends, along its axis. The lower ends of the two sets of the antenna cables are joined to the outer terminals on these brass tubes, the inner terminals being normally joined together and connected to the switch in the centre of the wall of the room. The antenna is thus in the normal connection a "fan" antenna. The centre switch enables the antenna to be joined to (1) the spark sender, (2) the Poulsen arc sender, (3) the earth, (4) the receiving side.

The earthing wire, used for sending and receiving, is a thick cable proceeding through the floor out to an extended lead roof over a corridor.

The spark sender consists of an 18-in. Apps' induction coil, which can be excited from the city alternating supply (100 volts) through a suitable resistance, or, using a mercury or other break, by means of storage cells up to 100 volts. The sending circuit includes a capacity of large Leyden jars arranged in parallel and series. This condenser discharges through an inductance consisting of a few turns of a helix of stout copper tubing and various types of spark-gap. The capacity and inductance are adjusted for a wave length of 600 metres. At present the coupling with the antenna circuit is direct, as it is usually in the Braun sender. Such a number of turns of the helix are included in the antenna circuit as to produce the correct wave length. Weak coupling is provided by making only one or two turns of the helix common to the closed oscillation circuit and the antenna circuit.

The Poulsen arc generator is of an experimental type, having a separately excited magnetic field which can be varied over a wide range. The arc is struck between the usual copper and carbon electrodes inside a closed chamber with marble sides, with means for admitting hydrogen, coal gas, etc. The suitable atmosphere can

also be provided by means of a spirit dropper which allows alcohol to drop on to the copper electrode, or into the arc near the copper. The arc is fed from the city direct-current 240- or 480-volt mains through regulating resistances, air-cored choking coils being introduced to prevent the oscillations passing to the supply mains. Under normal working conditions one terminal of the arc is connected to earth through a large capacity (block condenser), the other terminal being connected through a similar condenser to an inductance and capacity which are connected to the antenna. The capacity, which is in parallel with the inductance, is an oil condenser, and both it and the inductance can be changed to give various wave-lengths up to 1,500 metres. The sending key is arranged to short circuit either an extra capacity or an extra inductance in the antenna circuit, so as to produce the variations in wave length by means of which signalling is effected on the Poulsen system.

For the receiving circuit, a primary coil, wound with No. 14 wire over an ebonite cylinder (12 in. diameter), is arranged with its axis horizontal. Spring contacts connect the turns of the coil in use to the antenna and to earth, a variable condenser being arranged in parallel with the coil. By means of a double-pole change-over switch, the variable condenser can in a moment be changed from the above connection and put in series with the coil between the coil and earth. In this way the wave length can be adjusted between wide limits from the lowest wave length used in wireless telegraphy of about 300 metres up to the highest used by Marconi of nearly 4,000 metres. Inductively coupled with this coil is another coil, sliding within it, also wound on an ebonite cylinder but of slightly smaller diameter. To this secondary, which can be closely or loosely coupled to the primary by sliding it in or out along guides, are connected the various detectors, electrolytic, thermoelectric, etc. Near one end of the primary coil is arranged another secondary wound on an ebonite cylinder (13 in. diameter), with a finely stranded conductor consisting of 21 strands of No. 35 silk-covered wire. This secondary is intended for use as the receiving circuit for the undamped Poulsen waves. Variable condensers are joined to the turns of this secondary coil, and adjustment of the wave length is made by means of contacts on the secondary and the variable capacity. By means of a Poulsen "tikker" the energy, accumulated by resonance, intermittently charges a condenser across which is the receiving telephone. The coupling between the tuned primary and secondary of the Poulsen receiver is varied by the rotation about a vertical axis of the secondary before one end of the primary coil, whose axis is horizontal.

The development of the Armstrong College experimental station will, we trust, afford facilities for studying radiotelegraphy, and for making investigations in connection with the subject.

As previously mentioned, recent progress has been largely in the production of persistent or undamped waves. The advantages claimed for the Poulsen arc undamped wave system are (1) that,

owing to the persistent effect of undamped waves, the receiving circuit can be very loosely coupled to the antenna circuit, and thus rendered very insensitive to atmospheric electricity, or to undamped waves of wave length differing by even a small percentage from those for which the receiver is adjusted, (2) the potentials imposed on the sending antenna are only a few thousand volts, and only a few hundred volts are used in the sending system.

Following upon Poulsen's arc method and Fessenden's high-frequency alternator for radiotelegraphy and telephony, we have Marconi's high-speed discharger. The arc is only able to produce very high-frequency oscillations when means are supplied for quickly getting rid of the heat liberated in it. Poulsen effects this by conduction, using a water-cooled copper electrode as anode. Marconi effects this by a convection method.

The new Telefunken "shock excitation" system based on Wien's "quenched spark" 1906, has proved a great improvement on the ordinary spark method. In the ordinary spark method for the production of electric waves, reaction takes place between the primary spark circuit, as long as the spark lasts, and the secondary antenna circuit, this reaction resulting in the production of waves of two wave lengths. In the new Telefunken system, advantage is taken of the very large damping of a series of very short sparks. The primary oscillations are "quenched" by this damping after but one or two swings, and the secondary circuit continues to oscillate in a single period, giving rise to an electric wave of definite wave length. An alternator having a frequency of the order of 1,000 per second produces, by means of a transformer, a very high number of discharges per second. One of the principal advantages of this system is the musical tone produced in the telephone at the receiving end, this is distinctive of the station transmitting, and very different from the noise of atmospheric disturbances. (*Electrician*, vol. 63, Count Arco, p. 370; Fleming, p. 332; Eccles, p. 617).

The problem of directive wireless telegraphy has made considerable advance towards solution by the experiments of Bellini and Tosi, who have constructed a complex antenna, by means of which the waves are sent almost entirely in one direction. Similarly at the receiving antenna they can locate the sending direction. In their first arrangement two triangular antennæ, open at the top, are supported from one mast. The planes of these antennæ are perpendicular. When oscillations are set up inductively in coils included in the bases of the triangles by means of a single coil that can be turned in different directions, the radiation is greatest in the plane of the moving coil. Considering each antenna separately, the radiation is greatest in the plane of that antenna, but with both antennæ the radiation is greatest in the plane of the coil inductively coupled with the antenna coils. The arrangement is called by Bellini and Tosi a radiogoniometer.

In their final arrangement the radiation is confined almost entirely to the one side of the transmitting direction by employing an ordinary

vertical wire antenna in conjunction with the above. The curve of radiation may then be made of the form of a cardioid with the antenna at the cusp, instead of the figure of 8 curve given by the first arrangement. Experiments with this system were made with satisfactory results last year between Dieppe and Havre, and Dieppe and Barfleur.

Wireless telegraphy has special fields of its own, viz., communication between ships, and between ships and shore, and communication between places between which it is difficult to lay cables, as well as the fields already served by means of telegraphic wires.

The transmission of news to ships at sea renders it possible to publish daily on the various liners several editions of a newspaper, and it is important to note that the same message can be transmitted simultaneously to any number of stations that are provided with suitable receivers, and are within the range of the sending station. Moreover, radiotelegraphic communications are independent of the many causes that interrupt wire telegraphy, such as snowstorms, hurricanes, etc., on land, and cable accidents at sea.

At the present time wireless telegraphy forms an indispensable adjunct for warships, as well as for the great liners crossing the ocean, and soon, no doubt, no ship will proceed to sea without this invaluable method of communication.

We may also note that, by the receipt of weather reports from ships at sea at definite times, it will be possible for the meteorological authorities in England to obtain the advantages that have previously only been possible to countries of vast extent, such as America, and thus to be able the more exactly to predict the weather.

It has also been proposed to send signals at pre-advertised times from the Eiffel Tower, say at midnight, when there is least liability to interference, and thus ships in the Atlantic could receive the correct time necessary for determining the longitude.

Before concluding my address I desire, if I may be allowed to do so, to offer a high tribute to the numerous valuable expositions of the subject contributed by Professor J. A. Fleming, F.R.S.

At the conclusion of the address, which was illustrated by experiments and slides, an inspection was made of the College station, and, through the co-operation of Mr. Sörensen, a demonstration was given showing how the Poulsen waves, being made intermittent at the transmitting station at Cullercoats, actuated an ordinary spark receiver.

THE ELECTRIC IGNITION OF INTERNAL COMBUSTION ENGINES.

By JOHN W. WARR, Associate Member.

(*Paper received from the* MANCHESTER LOCAL SECTION, *October* 15, *and read at Manchester on November* 2, 1909.)

CONTENTS.

The effective running of the petrol motor is, of course, dependent on the concurrence of many factors, but the most important are probably correct proportions and volume of the mixture of vapour and air, high compression, and correct timing. All these are favourable factors contributing to efficiency and a sudden inflammation period. The temperature and construction of the igniter is largely conducive to the instantaneous application of force at the back of the piston, and it is to this alone that our attention is directed. As the old tube ignition may be said to have completely disappeared, the only method left for consideration is electrical ignition.

There is not the slightest doubt that in whatever form it is applied, electric ignition is a notable advance on what previously existed. It provides absolute immunity against fire, the spark is well suited to the explosive mixture, and the charges which are so weak as to give irregular impulses with the hot tube can be fired with absolute certainty. Further, an increased efficiency is obtained by being able to fire the charge at the moment of maximum compression, it admits of automatic timing and consumption of current and the use of higher compressions.

The electrical ignition of all modern automobiles is produced from either a primary or a secondary current. The primary current is,

of course, a low-tension one, and the devices that can be used may be tabulated as follows :—

1. Accumulator.
2. Accumulator and series coil.
3. Magneto.

The hot-wire system, which is named "Catalytic Ignition," has never been put into commercial operation, but a brief description of the apparatus, as shown in Fig. 1, will no doubt be interesting. The battery "B," which must necessarily be of large capacity, has a fine platinum wire "C," made up similar to the present high-tension plug and a sliding rheostat "R," connected in series with it. Cutting in and out resistance respectively decreases and increases the temperature of the platinum wire which advances or retards ignition due to the interval of time that elapses before the wire has sufficiently reached

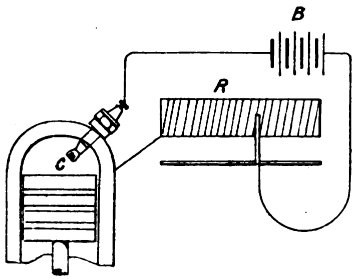


FIG. 1.

its correct temperature to inflame the mixture fully. The great disadvantages are : the large current required to bring the platinum to the required temperature, liability of fusing the platinum by over-running the resistance, waste of energy in the resistance, inflexibility and the uncertain inflammation capacity. The weakness of this system will be clearly indicated by the fact that the advancement and retardation of ignition is not nearly so perfectly controlled as the systems to be considered.

The accumulator alone with a pressure of 4 to 6 volts appears to be one of the very earliest devices, but owing to the large current taken on short circuit, the ignition points were quickly destroyed, and the high temperature of the points set up by the large current frequently caused premature ignition. This was more marked with high compression. Of course, large capacity cells were necessary, and on account of heavy duty they had to be of massive construction.

Later the accumulator and series coil was introduced, the presence of self-inductance or extra current making its appearance as a bright hot spark at the tappet points at the moment of breaking circuit. The

coil consisted of nothing more than several turns of No. 16 S.W.G. cotton or silk-covered copper wire wound on a wooden former with a bundle of soft iron wire in the centre. This was an improvement in the right direction, at any rate as regards the reduction in battery capacity, but the appearance of a reliable low-tension magneto probably crushed it out of existence.

The low-tension magneto driven from the cam shaft was rapidly brought forward, perhaps on account of the necessary recharging of the accumulator and other attendant evils which the electrical profes-

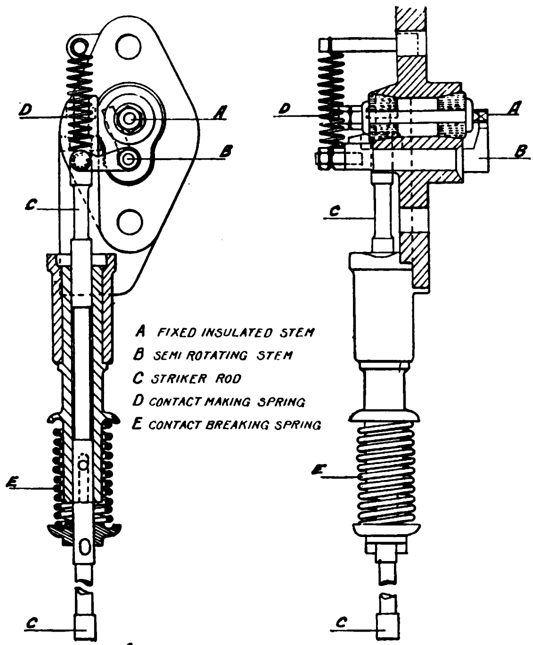


FIG. 2.

sion are well acquainted with. Even to this day there is diversity of opinion with motorists as to whether the magneto has any advantage over the accumulator.

Contrary to the high-tension system, all low-tension ignition has to be operated with mechanical make and break tappets from the cam shaft. Tappet gears of present-day design differ very much from each other, and in each case the patents are the property of the motor manufacturers. The gear shown in Fig. 2 is representative in principle of those used by leading builders and is attached vertically to the sides of the cylinder. The fixed insulated plug is shown at "A" and can be made and screwed in the plate in a similar manner to the

modern high-tension plug but having only one electrode as shown in Fig. 3. The tappet "B" is also fitted into the plate to rotate through a small arc, both "A" and "B" projecting into the combustion chamber. With the striker rod "C" in the normal position, the tension of the spring "E" keeps the contacts apart internally. Shortly before ignition takes place the cam raises the rod "C" through an intermediate pusher rod, not shown but fixed directly underneath "C," and allows the spring "D" to bring the internal contacts together. A step in the cam then passes the foot of the pusher rod, and allows rod "C" to fall quickly, due to the influence of spring "E." The momentary making of the circuit is at once followed by a quick break, thus producing a spark at "A" and "B." As a rule in multi-cylinder engines the

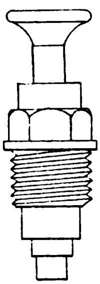


FIG. 3.

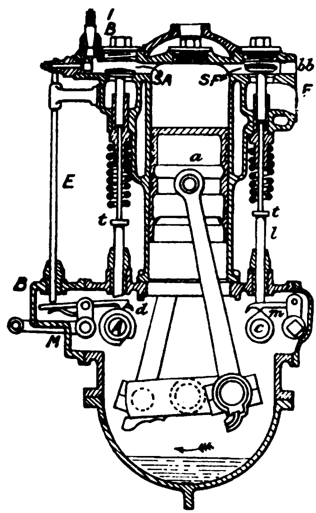


FIG. 4.

insulated plugs are all electrically connected in parallel from a common busbar through a knife switch, so that any individual cylinder can be disconnected for testing the action of the tappets when the engine is running. By the use of the busbar only one lead is necessary from the magneto.

A simple method of retarding and advancing the tappets of low-tension ignition is shown in Fig. 4. "IB" is the insulated plug, and directly below the tappet is fixed at right angles which is connected to the striker rod "E." The foot of the rod "E" rests on the follower "*d*" at "B" and when the V-shaped end of the follower falls into the stem of the cam "A" on the half-time shaft, the tappet points make circuit. Immediately the V end of the follower mounts the symmetrical surface of the cam, circuit is broken, thus producing a spark and firing

the mixture. A flat spring holds "*d*" in contact with "A." It will now be clearly seen that the cranked lever "*m*" can rotate the follower through a certain arc on the cam "A" thus retarding or advancing ignition when desired, the operation being controlled from the steering

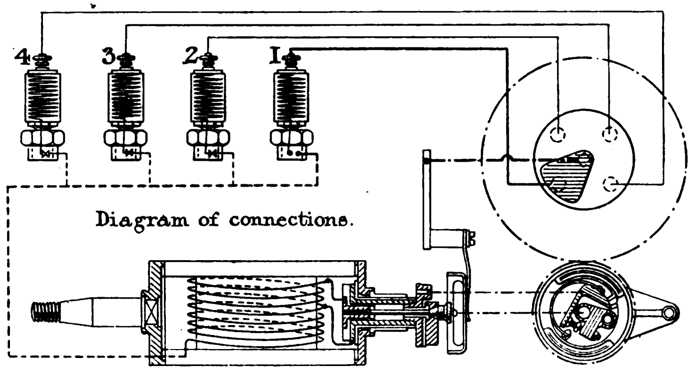


FIG. 5.

pillar. Some car builders with low-tension ignition permanently fix the period of firing so that no adjustment to suit high or low speeds is obtained.

In order to dispense with complicated mechanical striking gear and

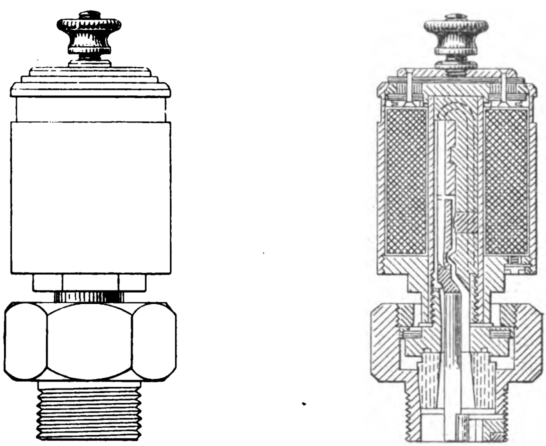


FIG. 6.

tappets, magnetic plugs or electrical tappets are used. The plug and diagram of connections is shown in Fig. 5. A section of the plug is shown in Fig. 6. The current is generated in the two windings of the revolving armature from the permanent field, and attains a maximum

voltage twice during each revolution, the two maxima being 180° apart and producing two sparks per revolution. The armature is driven at crankshaft speed. In the diagram of connections the dotted

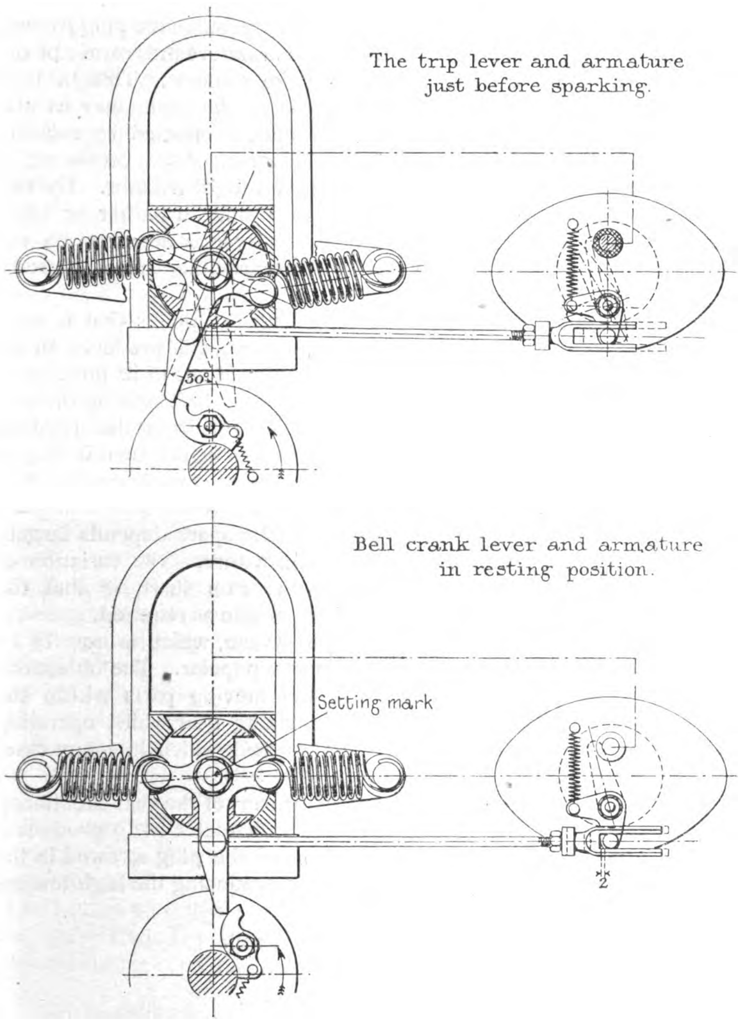


FIG. 7.

lines represent the completed circuit by the car frame. On the right-hand side of the armature is shown the contact breaker through which the auxiliary winding is periodically short-circuited just previous to the current attaining its maximum. At the moment of short circuit a sufficient current in the main winding to attract the plug interrupter

is not produced. However, when sparking is to take place within the compression space of the cylinder, the platinum points of the contact breaker are severed, the current in the main winding being suddenly reinforced by the extra current of the auxiliary winding. Thus a powerful current flows through the coil of the magnetic plug by way of the distributor, vigorously attracting the armature interrupter of the plug and effecting a quick breaking of the contacts. This in turn produces a powerful and very hot spark in the same way as the mechanical tappets. The variation in timing is effected by rotating the lever embracing the make and break contacts shown on the right-hand side of the drawing, directly below the distributor. By this means the interruption and the spark are produced earlier or later. For a 4-cylinder engine the rotation of the lever is about 50° on the crankshaft. The engine is stopped by short-circuiting the armature to the frame through a single pole-switch.

There is just one other low-tension magneto igniter that is used chiefly with single cylinder engines. The current is produced by an oscillating motion of the armature and is moved out of its position of rest through an angle of 30°, a thumb on the cam shaft striking the trip lever on the armature shaft. The horizontal springs bring the armature into its normal position. The whole arrangement is shown in Fig. 7, including the striking rod, which operates the mechanical tappets. The tappets break circuit when the armature has passed a few degrees beyond its normal position. The length of the spark depends largely on the swiftness of the movement of the armature. The variation of ignition is obtained from a device on the cam shaft, so that the releasing of the trip lever takes place early or late as required.

In comparison with the high-tension system, which is now to be considered, the low-tension ignition is not so popular. The objections are: wear of the tappet points and the moving parts within the combustion chamber, wear and tear of striking gear whilst operating at high speeds and constant need of adjustment, which in many cases can only be perfectly carried out by experts.

The high-tension ignition does not require any of the gear mentioned above, the apparatus used being of such a character as to produce a flaming jump spark between the electrodes of the plug screwed in the combustion chamber. The means used for producing the high-tension spark are:—

1. Battery and induction coil.
2. Magneto and induction coil.
3. High-tension magneto.

The battery and coil ignition is so well known that it not necessary to go into lengthy details concerning them. With the modern ignition accumulators we have compactness and fairly large capacities. The celluloid case enables one to see the condition of the plates at any time, and especially during the progress of charging. On the other hand, acid spray and bad joints between the celluloid and the lead

terminals has brought them into great disfavour with a large number of motorists, the acid playing havoc with everything that comes in its way. Then we have the question of recharging. If every motorist and the persons who usually charge ignition cells knew how to deal scientifically with the accumulators given into their care, we should not have such reports of their behaviour on the road. Too much reliance is placed on the voltmeter reading after charging, and unless the cell is doing service on its own coil or a suitably closed circuit, a fictitious reading is likely to be the result due to recuperation characteristics. How many persons take readings of each individual cell, or how many make observations of the colour and condition of the plates? Then there are shorted plates due to disintegration of the active material which usually appears at the bottom of the cell, undercharging, over discharging, bad acid, and laying the cell aside for a long period in a semi-discharged state. It is doubtful if the accumulator is so black as it is painted. The average motorist is not expected to know all the technical details of the accumulator, yet he should be credited with having and using common sense. When this is brought into use together with careful and discreet handling, the motorist can depend upon it that troubles will materially decrease in number. The care required does not involve expert care but reasonable care. In view of the fact that recharging can now be expeditiously carried out at nominal charges by the various supply anthorities, the accumulator is not likely to be rejected for the present, and there are scores of cars, both ancient and modern, with accumulator ignition that are likely to remain equipped in this way for many reasons, therefore manufacturers will do well to investigate the various details that contribute to its imperfection.

The primary dry battery has come into great favour lately, and there is no doubt it is being used with satisfactory results. The multiple cell giving an E.M.F. of 6 volts is suggested with a variable resistance connected in series with the primary of the induction coil and the battery, so that the pressure can be reduced to about 4 volts. When the battery has been used for some time the E.M.F. falls off. This can be detected by misfiring and instantly restored by cutting out a small section of the resistance, thus raising the E.M.F.

Some dry-battery makers recommend multiple series connections for heavy ignition service on automobiles. In determining the number of sets to be used it has been found best to use as many sets as there are cylinders. The following is a summary of the various ways of connecting :—

Single-cylinder, one set of four 1½-volt cells in series.
Twin-cylinder, two sets of four 1½-volt cells in multiple series.
Four-cylinder, four sets of four 1½-volt cells in multiple series.
Six-cylinder, six sets of four 1½-volt cells in multiple series.

Increased life is obtained by multiple series arrangement, due to the fact that the amount of current used by the coil is drawn equally

from each set. The objection to this system of connection will be the weight and accommodation.

Where it is difficult to get accumulators re-charged the dry battery is to be recommended if made by a reliable firm. The author has now used dry batteries for ignition for a considerable time with most encouraging results.

Induction coils may be divided into two classes, the plain type with primary and secondary winding and condenser, and the trembler type with the same internal equipment, but an external high-speed trembler is fitted to it. Apart from the fact that a multi-cylinder engine cannot be started on the switch with a plain coil, the timing seems to be more exact with a given piston position. In an experiment the author tried on a twin-cylinder engine with two simple make and break contacts and plain coils, steadiness of running was more distinct than with a rotary make and break. The improvement may be accounted for by the fact that the firing-point can be fixed more correctly, due to the platinum contacts being in use for a short and equal period, whereas with the segmented rotary make and break, the period of contact and unequal spacing cannot be made exactly alike. Further, since the segments have to be morticed into an alien substance—*i.e.*, brass and insulation—the wear is uneven, and metallic particles are carried in the insulation and give circuit when it is not required. A plain coil may be unintentionally left in circuit if the main switch is left closed, which is liable to burn out the coil and exhaust the battery. The trembler coil gives warning when left in circuit.

With the great number of cheap coils on the market, it is surprising that roadside troubles are not more frequent; what with imperfect tremblers and incorrect condenser capacity, the conditions are far from being satisfactory. It is generally supposed that the condenser is simply used to "absorb the extra current" from the primary winding. Though this is no doubt true, the best results are obtained when the self-induction of the primary and the capacity of the condenser are balanced, producing resonance. From results arrived at experimentally, the larger the current passed through the primary (which can be produced by overscrewing the contacts) the greater should be the capacity of the condenser. On the other hand, the gradual burning away of the platinum reduces the current in the primary and produces unbalanced effects with the condenser. Therefore, the desirability of an adjustable condenser seems clearly demonstrated. If the condenser is too small the secondary spark is short and feeble, with incurable sparking at the platinum. If the condenser is too large the spark is short and fat.

There should be no practical difficulties in the way of turning out every coil perfectly balanced, but until there are better means provided to adjust suitably the contact screw, excessive pitting of the platinum points is bound to take place when handled in ignorance.

In the hands of an expert the adjustment of a trembler blade apparently requires very great care. When testing a coil some time

ago, the ammeter connected in the primary showed that a current of from 1·5 to 6 amperes could be drawn from the 4-volt battery by altering the contact screw, and on closed circuit 15 amperes was indicated. In this instance, how could the motorist say which is the correct current, for both the 1·5 and 6 amperes produced sparks that appeared to have equal inflammation capacities? Inexperienced per sons adjust their trembler blades by the note that is produced from the rapid vibrations of the armature, a high, shrill note being considered the best. The author has proved that a moving-coil ammeter in the primary of the coil is the only guide, both as regards the most effective spark and economical current consumption. It is quite clear that the more pressure put on the blade by the screw, the nearer the contacts approach short circuit.

A very light fuse would be a useful addition in the event of the contact screw being lowered too far. This would indicate the presence of too large a current in the primary winding.

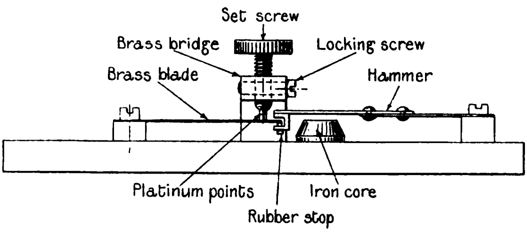


FIG. 8.

A trembler that will give absolutely perfect timing at a very high speed, that is not over sensitive to alterations and adjustments, and to give equally good results over a large range of setting is very desirable

After being in use for some time the platinum appears to leave the positive contact and builds up on the negative. A reversing switch would tend to keep the contacts level and do away with the filing of an expensive metal. Of the many faults in connection with ignition coils, internally punctured insulation of the windings and condensers make up a large percentage. The author is of opinion that a permanently fixed spark-gap would prevent a number of troubles, as the coil is very often operated with the secondary on open circuit by inexperienced persons when endeavouring to locate the causes of misfiring. A good type of trembler is shown in Fig. 8.

In either type of coil it is of the utmost importance to have an iron wire core that will admit of rapid changes of the magnetic flux. Lagging magnetic effects seriously hamper the period of inflammation. For instance, when the engine is running slowly it is possible to get correct ignition at the right position of the piston, but when running at high speeds ignition does not take place when expected, evidently due to the time taken to magnetise and demagnetise the core of the coil.

With an engine running under practically full impulse, ignition should occur just as the piston starts on the expansion stroke. Without considering any difference in compression pressure, and supposing the period of inflammation is $\frac{1}{120}$ of a second and the engine speed is 600 revs. per minute, then $\frac{600 \times 360^\circ}{120 \times 60} = 30^\circ$, or ignition should take place when the crank has still 30° to turn, *i.e.*, — $\frac{1}{12}$ of a revolution

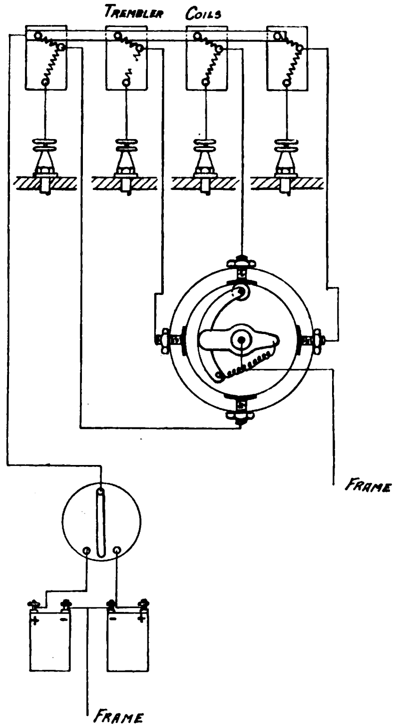


FIG. 9.

or 30° in advance of the dead centre of the piston. From this it is evident that when running at high speeds on the level with the spark correctly advanced, better results will be obtained when mounting a gradient in high gear by retarding the spark because the engine speed is lower.

We now come to the question of distributing the high-tension current in multicylinder engines. With the single cylinder this is effectively carried out by rupturing the primary current with a simple make-and-break contact on the half-time shaft. A common method is to provide a low-tension rotary wiped roller contact with as many points

of rupture as there are cylinders. This type is shown by Fig. 9 and makes and breaks circuit at the correct period in the primary circuit of the coils. The high-tension leads from the trembler coils go direct to the plugs. Levers and connecting rods rotate the fixed contacts through a given arc so as to produce early or late ignition. The sketch clearly shows all the connections, etc.

Another system consists of a combined low-tension contact maker and high-tension distributor, both being exactly synchronised and timed with the piston. Only one trembler coil is used. The contact

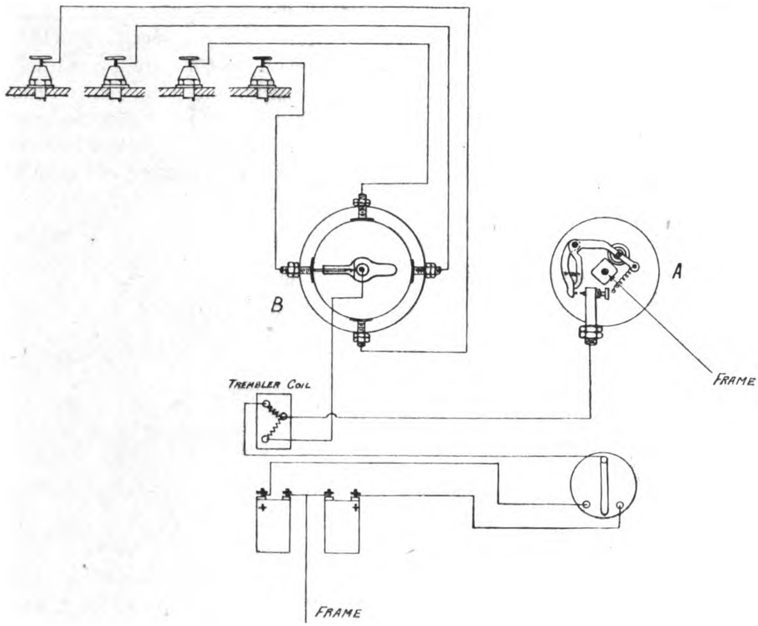


FIG. 10.

maker and distributor is driven from the half-time shaft in the same manner as the one mentioned above. The primary circuit of the coil is made immediately the contacts come together, which are shown separately at "A," Fig. 10, for clearness. The induced high-tension current is carried from the secondary winding of the coil to the centre rotary carbon brush of the distributor "B," through the stationary contacts, and away to the various plugs in the cylinders.

A high-tension battery system can be operated without trembler coils. As most of the troubles arise from the tremblers, this method has a great advantage over the others. A make-and-break contact is fixed to the half-time shaft similar to that illustrated by Fig. 10, and is capable of being moved to vary the timing. A single plain coil is

used, otherwise the connections and apparatus resemble those shown by Fig. 10.

When using the plain coil the timing is different to the trembler type. In the first case the primary circuit of the coil has to be made and then broken before the spark can be produced, and in the second case the primary circuit is made and immediately the spark follows by the action of the trembler blades.

Before leaving the ignition coil, the "B" spark being most interesting, deserves attention. The diagram, Fig. 11, displays the general principle of the igniter. The high-tension current is connected to the plugs through the intervention of two condensers with their outer coatings shorted through a leakage path or imperfect conductor, the object of which is to keep them always at the same potential, except at the instant of sudden discharge. No strain is thrown on the plug leads, they remaining at the same potential up to the last moment when the two condensers are full and overflow at "A." At this instant everything is liberated, and with great rapidity the condensers empty

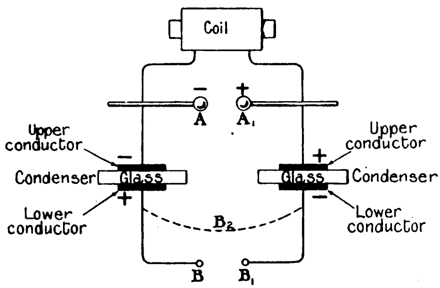


FIG. 11.

themselves across "A" and round the completed circuit to the sparking plugs and ignite the mixture in the compression space. The high-frequency discharge is so violent that soot round the plug electrodes is flung away, also the spark will blaze through water. An accumulator and induction coil with trembler blades furnishes the high-tension current for the condensers, and contrary to usual practice, the secondary winding of the coil is built up in sections. The coil only takes 0·75 of an ampere for a 4-cylinder engine, which is only a very small figure compared with other coils. Only one coil is used, the high-tension current being conducted to the cylinders by a high-tension distributor working on the cam shaft. Fig. 12 shows the general wiring diagram. Two tremblers are provided which work at each end of the iron core, but only one is in operation at a time, a single pole throw-over switch putting either one or the other in circuit. A reversing switch is also fitted so as to enable the platinum points to wear evenly. The system is a remarkable one for ignition purposes, as a spark, large in quantity, and thus more effective in inflammation

capacity, free from liability to short circuit with dirty plugs, and rapid in application, is undoubtedly obtained. The idea is due to Sir Oliver Lodge.

Two systems of magneto and induction coil ignition will be briefly referred to. The first consists of three main pieces of apparatus—viz., magneto, condenser, and induction coil. The current generated by

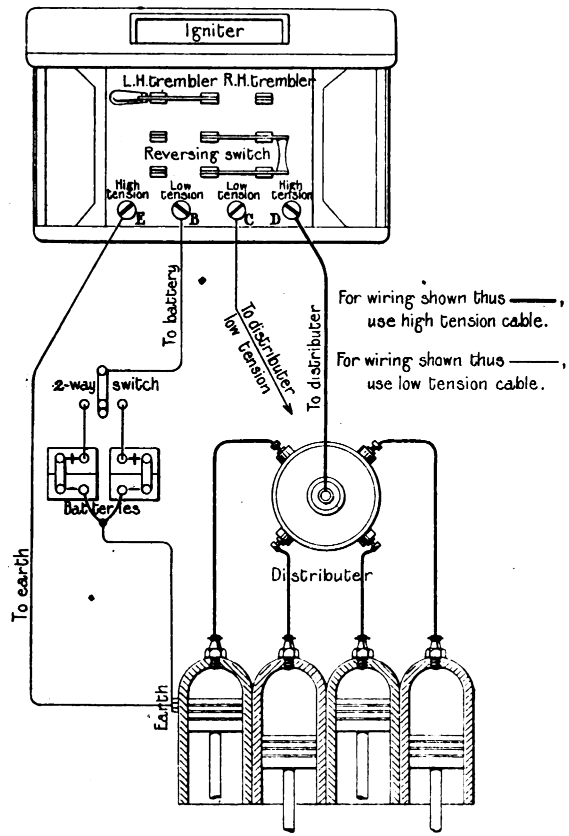


FIG. 12.

the magneto is stored in the condenser and discharges through the primary of the induction-coil inducing a high-tension current in the secondary winding. The voltage of the magneto follows more or less a sine law, and the commutator of the machine is so arranged that only the maximum voltage is taken off. It is not necessary to drive the magneto synchronously with the engine as long as the speed is sufficient to produce the required number of impulses to charge

the condenser fully. Fig. 13 is a diagram of connections for a 4-cylinder engine, the coils being of the trembler blade type.

In the second system, Fig. 14, a low-tension magneto and plain induction coil are used. The high-tension current is induced in the secondary of the coil on the sudden flow of current in the primary winding from the magneto.

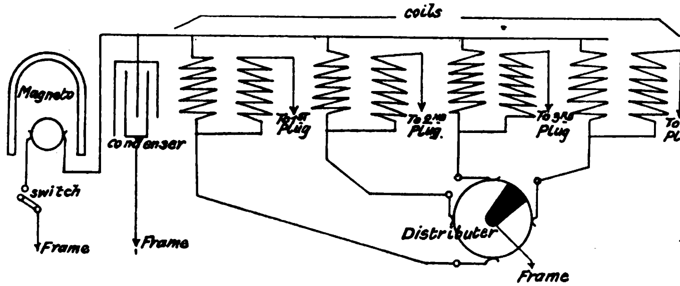


FIG. 13.

The low-tension current generated by the armature is short-circuited just previous to reaching its maximum. At the point when the mixture has to be fired, the platinum contacts open by a cam on the armature shaft, the impulsive current discharging in the primary of the coil and reappearing as high-tension current at the plugs by way of the secondary winding and a distributor. The distributor is

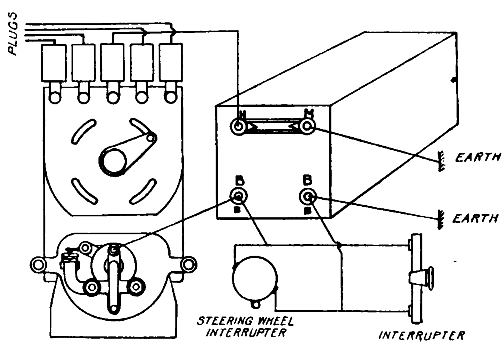


FIG. 14.

driven through gearing from the armature shaft. Interrupters are placed in circuit at convenient points to stop the engine. The armature is timed with the engine, and advance and retard are obtained from a rocker rotating round the cam centre on the armature shaft.

Probably the most popular form of ignition is the one in which the

high-tension current is generated in the winding of a rotating or stationary armature. This system is the simplest when compared with what has already been described. The diagram of connections in Fig. 15 represents a high-tension magneto for a 4-cylinder engine. Between the pole-shoes of the permanent magnets, rotates a shuttle-wound armature on which are two windings, a primary and a secondary, the latter forming a direct continuation of the primary. The alternating current generated in the primary winding attains its maximum twice during one revolution, the two maximums being 180° apart. The high-tension current is produced in the secondary by short-circuiting and opening the primary circuit through the platinum pointed contact breaker twice in each revolution. At the

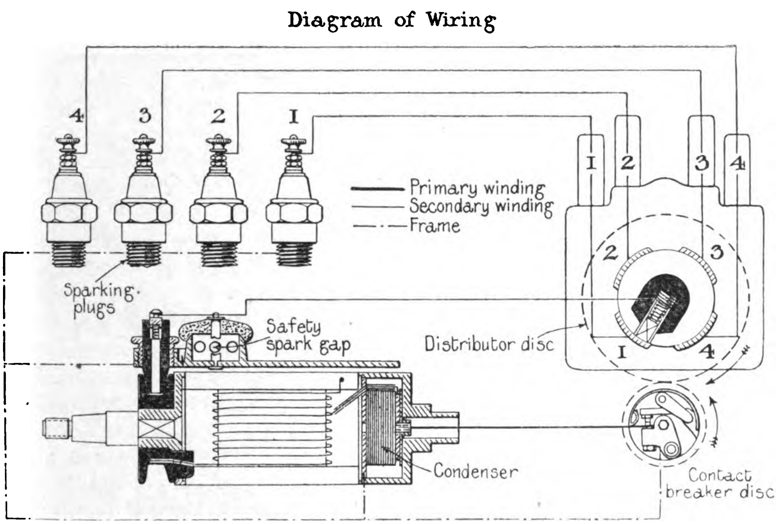


FIG. 15.

moment the circuit is broken the high-tension current is collected from the slip-ring by a carbon brush and taken to the distributor and plugs by the contact brush driven from the armature spindle. The armature is driven at crankshaft speed, so that when the winding is cutting maximum field its position must correspond to a definite position of the piston.

Another type of high-tension magneto, Fig. 16, is one in which the generation is based on the same principle as the well-known inductor alternator. The armature winding is stationary and mounted in the permanent field. A tubular soft iron inductor envelope having two slots cut in it, each representing a quarter of its circumference, revolves between the armature and the pole-shoes. By this means the current in the primary will attain its maximum when the inductor

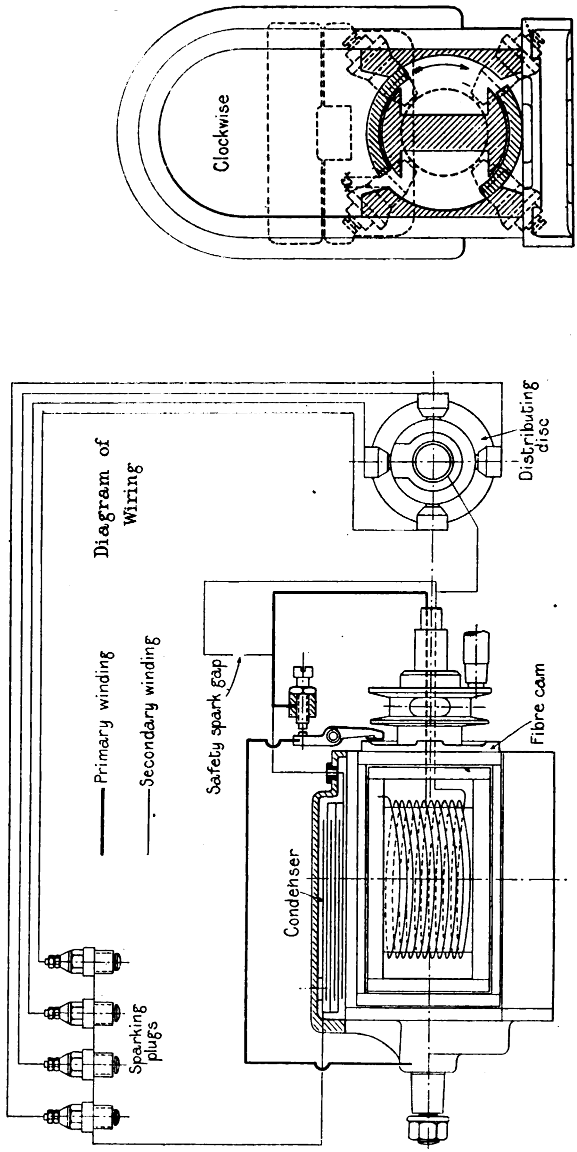

Clockwise
Diagram of Wiring
Primary winding
Secondary winding
Safety spark gap
Distributing disc
Fibre cam
Condenser
Sparking plugs

FIG. 16.

has rotated through an angle of 90° or four times per revolution. By rupturing the primary circuit during the effective periods a current is induced in the secondary winding four times per revolution. As no slip-ring or collector is required the high-tension current is conducted straight to the brush contact of the distributor disc.

The spark from high-tension machines of this class is more intense than that produced from ordinary induction coils. As an example the coil spark in one experiment was only just sufficiently powerful to ignite a mixture of petrol vapour and air in the proportion of 1 to 15, whereas the magneto spark was capable of igniting a mixture of 1 to 19.

As in the case of coil ignition the timing with a high-tension magneto must be set to occur early. The spark can be advanced or retarded through a small angle varying from 25° to 50° according to the number of cylinders.

Some of the machines have a condenser connected across the make and break, but in all cases spark-gaps are provided. Ball bearings can be fitted if desired, which, needless to say, are infinitely better than the sleeve bearing. Wherever possible gear drive should be used—chain and sprocket wheels severely punish either type of bearing.

The chief advantages of magneto ignition are: an inexhaustible source of current, the induced current is directly utilised, and the sparks have a higher temperature. The vital parts are not scattered in different parts of the car as is the case with the coil and accumulator ignition. With a spare magneto carried in the car the faulty one can be removed in a few minutes. On the other hand, it must be remembered that the magnets require reflashing periodically, bearings and platinum contacts require attention, a perpetual load is always on the engine, and the adjustment in the timing is not so flexible as with the coil. Troubles do not end when you have a magneto, for, like the accumulator and coil, they require discreet handling.

In all the systems mentioned dual and even triple ignition can be fitted. In one instance brought under the author's observation high-tension and low-tension magneto and accumulator ignition was suitably arranged. In any case it is common practice to provide accumulator and coil ignition for starting the engine, afterwards throwing over to the magneto. Some car builders use a high-tension magneto without its combined high-tension distributor. The arrangement used is similar to that described by Fig. 10. The single trembler coil and battery is used to start the engine, after which both are cut out of circuit and the magneto switched in.

A very ingenious device has just been introduced for starting. The principle is based on temporary use of the primary and secondary winding of the high-tension magneto armature as an induction coil. Current from a dry battery furnishes the current which is conducted by suitable switchgear to the armature primary winding. If the engine has to be started after it has not been working for a few

days, a turn of the handle is required to rupture the dry battery current in the primary winding, but if a charge is left in one of the cylinders previous to running, the pressing of a button switch will start the engine whilst the driver is seated. The author is of opinion that energising the armature in this way will in time reduce the field strength of the permanent magnets.

Discussion.

Mr. Walthew.

Mr. J. G. Walthew: The paper placed before us this evening has been most interesting, and particularly instructive from an electrical point of view, the author having brought out very clearly the comparative efficiencies of the high- and low-tension systems for ignition. As regards motor-cars, the low-tension system has many advantages over the accumulator and coil, or high-tension system, and as the author points out, should the accumulator fail, it might be impossible to get it recharged, and in any case, there would be delay, assuming that only one system of ignition is fixed on the car. With large stationary multi-cylinder gas engines, the high-tension ignition system is undoubtedly the best.

The chief fault with the low-tension system is that with large engines the ignition gear contains comparatively heavy moving parts, which set up wear and tear, and this is a frequent cause of complaint. Consequently if one can provide a system of ignition that is practically free from wear and tear, I think that point alone is sufficient to recommend its adoption, at all events upon multi-cylinder engines. In stationary single-cylinder gas engines the low-tension magneto system probably has the advantage of simplicity, and providing that wear and tear is not allowed to take place unnecessarily, then I consider that the low-tension system is all that can be desired for a single-cylinder engine. From the user's point of view, complaints are made that the wear both on the tappets and on the sparking-points is in excess of what it should be; but it is generally found that this is due to bad setting of the contact maker and breaker. For instance, the sparking which takes place in the ignition box, should not be more than about $\frac{1}{16}$ in. at the outside; if there is more, the spring which returns the contact maker into position necessarily brings it back with such force as to cause wear, and instead of $\frac{1}{16}$ in. breaking contact one may get $\frac{1}{8}$ in. or even more than that, and so the thing aggravates itself, and we naturally get complaints of excessive wear. That is one of the faults of the low-tension make-and-break system of ignition. Another fault of the low-tension system when in use upon engines is that it is possible to fail to get a spark from the low-tension plug, if the small moving contact maker should become coated with dust or dirt, which just for the moment may arrest the electric connection, although by merely removing the contact maker and cleaning the stem, or even brightening it with emery cloth, a proper electrical contact is made. Now with the high-tension ignition one does not have those troubles. The objection to the high-tension ignition

is the trouble which the accumulators sometimes give, and for this reason it is interesting to hear what the author had to say about using a dry battery, and it would be interesting if he could give us some further information as to whether a dry battery could not be made of small proportions, and at the same time of reasonable weight for a given capacity, so as to replace the accumulators at present in use, which seem to be the weak spot in the high-tension system. Mr. Walthew.

The author's remarks upon the troubles with the induction coils are very instructive indeed, especially as little information can be obtained from the coil makers. The varying amount of current required seems to be according to the adjustment of the contact screw. From a test I found that the current necessary with a 6-volt primary circuit varied from about 2 to $3\frac{1}{2}$ amperes, when the trembler blade was working practically the whole time, so that the figure of $1\frac{1}{2}$ to 6 amperes which the author gives in his paper bears out that test pretty well. I should like to ask the author what he means by re-flashing of the magneto, how this is done, and how often it should be done? Then again, will he state which is the best form of contact maker or commutator for the high-tension system, whether he considers the wipe contact is better than the sliding contact. The latter is made on similar lines to the commutator of a dynamo and has brushes. I have seen this form of commutator in use, and when it is in an engine-room, in which the atmosphere may not be quite clear, particles of dust settle on its surface which requires constantly cleaning. That trouble does not arise with the wipe contact nearly to the same extent.

Mr. J. FRITH: It is most useful to have the various systems of ignition set out clearly, with the advantages and disadvantages of each. In the hot-wire system of ignition, the drawing does not show any revolving contact maker; is there one in practice, or does the half-time shaft simply vary the resistance and so heat and cool the platinum wire? The accumulator mentioned a little further on, as one of earlier devices, probably worked through a make-and-break tappet plug, though this is not mentioned. I should like also to know if the electromagnetic tappet plug was in actual use, as the idea of using its magnet as the self-induction coil is ingenious. With regard to dry batteries to replace accumulators, I also have had much satisfaction from their use, but cannot recommend putting them in series parallel, as they tend to run down gradually owing to small differences in the E.M.F.'s of the cells in parallel. Mr. Frith.

In the experiment tried by the author, exactly which two systems are compared is not quite clear, perhaps he will enlarge a little on this. He says in the paper that an ammeter is the only guide in adjusting the contact maker of a trembler coil, but does not give any hint as to how the indications of the ammeter are to be used. Few motorists would willingly consent to a fuse in the battery circuit of their cars, with the possibility of the fuse blowing when going up a hill. I should like the author's opinion as to how much the spark should be advanced, as done from the steering pillar of a car, to overcome the

Mr. Frith. inevitable lag in the chain of events which causes the ignition, and what is the actual acceleration of the period of firing. I do not think it is good practice to employ only one coil to ignite a multi-cylinder high-speed engine, as the electromagnetic conditions of the coil can hardly be expected to follow quickly enough the changes required.

The author does not distinguish in the paper between those magnetos which always use the most effective position of the armature for producing the spark and those in which the retarding and advancing of the firing-point prevents the crest of the E.M.F. wave from always being used. The question of simultaneously firing the charge at more than one point in the cylinder by means of two plugs in series, worked from the same coil or magneto, is engaging the attention of motor designers just now; can the author say if this is worth the extra complication of double pole plugs, etc., which it involves? By this I do not mean the firing from two separate plugs, the first of which, of course, always does the firing. Also, in the simple accumulator and coil system, does it matter at all how long the stream of sparks is allowed to flow after the explosion has actually started? Some time ago a system was introduced of putting an auxiliary spark-gap in series with the plug, with the idea that it made the firing more certain, and less affected by a dirty or leaking plug; does the author recommend this? In the accumulator and coil system, the earthing is generally carried out in such a way that it involves the passage of the battery current through the bearing of the half-time shaft. As electrical engineers know, an oil film can in some cases maintain a large voltage across it, so is it not always better to earth the shaft itself through a special brush?

Mr. Slacke. Mr. R. B. SLACKE: At the bottom of page 140 and again on page 141 the author refers to the troubles of accumulators; amongst others is the corrosion of the terminals. I think if he were to try vaseline cups under the terminals that would improve matters. I have tried this, and so far have not had any trouble. I quite agree with the author's remarks that most of the troubles of accumulators are due to undercharging and over-discharging, especially the latter. I am particularly interested to hear that dry batteries have improved so. Some four years ago I made a test of a French battery which was on the market at that time, and which was supposed to be a great thing. It did not compare at all favourably with accumulators. At the end of about three days' running on an intermittent circuit it was completely run down.

It would be interesting if the author could tell us what sort of mileage one ought to get out of platinum contacts on a trembler blade before bad pitting takes place. I have run now about 3,000 miles without any trouble, with the exception of giving a little brush up now and then. I am afraid I am one of those "inexperienced people" who judge the setting of trembler blades by the "buzz." I am surprised to hear that most of the faults in ignition coils occur in the windings,

because these do not move, and there is nothing to disturb them providing they are properly made in the first instance, and a pressure of 6 volts is not put on a 4-volt coil. Lodge ignition is being used a good deal, I believe, for motor-car work now. There is one other point as far as motor-cars are concerned, viz., the discussion as to the relative advantages and disadvantages of magneto and accumulator and coil. There is one thing in favour of the accumulator, although some speakers do not seem to agree with me on this point, and that is, if anything happens to a magneto on the road practically nothing can be done except to procure a new one. If a battery runs down, one can probably, by walking a few miles, obtain another; they are to be had everywhere, and also coils. The author mentions carrying a spare magneto, but a spare magneto is valued at something like £10 to £25, whereas a spare battery is about £2. Mr. Slacke.

With reference to the author's remarks on page 136 on the subject of the magnetic plug, there is a system on a somewhat similar principle now in use on the Continent for large gas-engine work. It is not exactly a low-tension system—*i.e.*, the actual voltage is from 60 to 100—but on a large gas engine it is practically the same as a low-tension system would be on a car. It has a mechanical tappet, but this is actuated by a solenoid. There are slip-rings on the cam shaft, and as each contact-piece in these rings makes contact with the brush, it closes the circuit round the solenoid, and also the circuit through the tappet, which in its normal position is closed, so that the effect of the solenoid is to open the tappet and let it shut again, thus getting the spark. The tappet itself is of cast iron, and it does not seem to have given any trouble from wear. Several makers of Continental gas engines use the system. There is a brush rocker for altering the timing, which, however, is not used for regulating the speed of the engine as in motor-car work, but is advanced or retarded as the mixture is weak or rich, because it takes longer for complete combustion to take place with a weak mixture than with a rich one. One or two Continental firms have had experience with Lodge ignition, and in at least one case this has now been adopted in preference to the other, and has been found very satisfactory.

Mr. H. ATKINSON: I have had a certain amount of experience in Germany with both low- and high-tension electrical ignition for large gas engines. Just lately I had the opportunity of examining some low-tension plugs which had been withdrawn from the cylinders. One of the chief faults seemed to be that the two surfaces of the fixed pin and moving lever did not always exactly coincide. One is apt to overlap the other and thus a ridge is worn, and owing to this ridge uneven firing is set up. It is usual to time both ends of the cylinder with one apparatus, and if one plug is worn more than another, or if one has a ridge and the other none, then it is easy to see that they cannot fire regularly. The consequence is that they must often be drawn and filed. The Lodge system has been used over there by Messrs. Erhardt & Sehmer with, I believe, good results. In general, Mr. Atkinson.

Mr. Atkinson. opinions on this system are somewhat conflicting. Some people give it an excellent name, whilst others have discarded it; the latter result was, I should think, due to faulty handling. With regard to magneto ignition, the old type worked very well, and I have run Siegen-Koerting engines on this system night and day for six or seven weeks without a stop. The great fault of this type, however, on the old engines was that the driver was apt to remove part of the mechanical drive with his feet when climbing over the engine, and this is a great disadvantage when blowing on to a blast furnace. I think that the high-tension ignition is that which will be soon used generally.

Mr. Cox. Mr. K. R. H. Cox: Mr. Walthew remarked that the only weak spot in the high-tension system was the battery. I think the coils also have certain weak spots, and I do not consider the battery is always the culprit of the system. With regard to wipe contacts, Mr. Walthew made a remark to the effect that he did not think the wipe contact quite as satisfactory as the make-and-break contact. The wipe contact is, I think, fairly satisfactory, but with the make-and-break the great trouble is the actual burning that takes place. The brushes burn very badly, and have to be replaced very often. If the wipe contact was made of a suitable material, there would be very little trouble experienced with it. One speaker made a remark about spark-gaps. It certainly is an advantage to have a gap on the outside, especially in multiple-cylinder engines. It gives one a chance of actually seeing if there is a plug misfiring from any external cause.

Mr. Cowell. Mr. R. Cowell: I should like to question the author's statements about the relative advantages of the magneto and battery. My experience with cars has been that very much more power has been obtained with the magneto ignition than with the battery.

Mr. Stelling. Mr. A. R. Stelling: The author does not appear to have emphasized the relative merits of oscillating and rotating shuttles in magnetos. Personally I am in favour of the oscillating shuttle, combined with what the author describes as an inductor envelope. The great advantage of this envelope, when combined with the oscillating system, is the very small moving mass, and in consequence the very slight mechanical reaction; whereas with an ordinary wound oscillating shuttle there is apt to be unnecessary vibration, and, further, the wires are likely either to break down the insulation or to break loose altogether. Comparing the oscillating types and revolving types, another advantage of the former is that very accurate timing is possible. As Mr. Frith pointed out, one is apt, with the rotating type, to be compelled to make use of an undesirable portion of the E.M.F. wave, whereas with the oscillating type, and by adjusting the tappet, it is always possible to take the current at the top of the wave. Moreover, with the rotating shuttle the E.M.F. varies with engine speed and cannot be used for starting up. Bearing troubles are not so great on the oscillators.

It is surprising to me that better use is not made of the well-known electrical fact that in breaking a circuit a larger and better spark is

obtained than in making a circuit. There is a system which, I believe, is due to Bosch, of Stuttgart, in which he makes use of this. There the armature is permanently short-circuited by means of a cam, and only at a certain portion of the cycle is contact suddenly broken. This is used in conjunction with a condenser, and gives a very good spark indeed. Mr. Stelling.

Referring to page 143 of the paper, may I ask whether there is not perhaps a printer's error, or some explanation needed, where the author states "that a permanently fixed spark-gap would prevent a number of troubles, as the coil is very often operated with the secondary on open circuit." Surely it should not damage the coil if the secondary circuit is open. As regards the spark-gap in series, I have had this described to me by a gas engineer who was experimenting with a spark-gap in parallel outside the cylinder. He was working on the principle used in wireless telegraphy of having two oscillating circuits in parallel. I do not know whether the author has had any experience with spark-gaps in parallel, but perhaps he will be able to give us some information on the subject. In conclusion, I should like to question the author's statement that "the only method left for consideration is electric ignition." Is it not possible to use a chemical action for ignition whereby at the moment when explosion is desired some other gas or fluid can be injected into the cylinder to cause the explosion? I do not know whether that has ever been tried, but it seems a feasible idea.

Mr. H. J. COATES: Referring to pages 147 and 148, Fig. 13, the coils there are described as of the trembler type. Now it is quite immaterial in this case whether a trembler or non-trembler coil be employed, because the discharge of the condenser is so extremely rapid that the trembler does not function, as the inertia of the trembler blade is not overcome before the discharge is over. It is obvious that a plain coil consisting of a core primary and secondary only will work equally well. The action depends, in this system, on the sudden setting up of a magnetic field by the discharging of the condenser through the primary when the contact is made, contrary, of course, to the usual action, in which a magnetic field is suddenly destroyed by the opening of the contact. In magneto ignition systems it appears to be now the standard practice to place the high-tension winding over the armature winding. Now, whilst this construction lends itself to extreme compactness, it may be well open to doubt if this really is the best place in which to fix the secondary winding where the difficulties of sound insulation are often considerable, in spite of the limitation of the voltage rise due to the provision of a protective spark-gap. In some few makes, I believe, it has been the practice to place the transforming element over the armature-box underneath the arch of the magnets; certainly this disposition appears to be a better one for providing effective insulation and reducing the risk of breakdown. Mr. Coates.

On pages 142 and 143 the author refers to troubles with multi-coils of the trembler type, particularly with regard to the difficulty of obtaining

Mr. Coates. the best timing results. I am of opinion that with such systems only one trembler, common to all the coils, should be used. Fairly heavy contacts would, of course, be necessary, as the work would fall on one pair of contacts instead of two, three, four, or even more, as the case may be, but by the provision of a reversing switch, as the author mentioned in his paper, the direction of the flow of current could be often changed, and pitting could be very largely prevented. Where coils are already installed, this effect of good timing might easily be obtained by the employment of an auto-trembler, which might be placed in the circuit, and the ordinary tremblers thrown out of use by being screwed hard down. With really good coils, and a suitable auto-trembler common to them all, little difficulty should, I think, be experienced in running with a current of even so low as half an ampere, and with such a small current there would be very little trouble from pitting contacts.

Mr. Watson. Mr. S. J. Watson: After reading through the paper, and seeing one or two diagrams which have been put on the blackboard, I have come to the conclusion that useful work might be accomplished in simplifying the ignition gear; there are at present too many links in the chain between the mechanical operating gear and the sparking plug.

With regard to the low-tension and high-tension systems, I should like to ask the author what pressures he refers to as low and high. From the remarks made, low-tension in some cases means about 4, and in other cases about 100 volts, and high-tension in one case is referred to as being about 1,000 volts. Taken altogether, the paper is undoubtedly a valuable one, but, speaking generally, I do not think it would be advisable for information of this kind to become public property. If a probable purchaser of a motor-car happened to read an account of the complicated electrical apparatus which he would have to attend to, in addition to the mechanical portions of the engine and gears, he would very likely be deterred from making the purchase.

Mr. Warr. Mr. Warr (*in reply*): With regard to Mr. Walthew's remarks, I should always prefer high-tension ignition for motor-cars and also for stationary engines. The methods of producing the low-tension current itself undoubtedly tends to simplicity and is a great recommendation, but its application in connection with intricate striking and tappet gear operating at high speeds on the one hand, and heavy slow-moving masses on the other, must set up excessive wear and tear. Gas-engine tappets are more unreliable than those used on the automobile because they are more rapidly coated with the products of combustion. The points when coated in this way become insulated and produce open circuit. The high-tension spark will easily penetrate any coating of this kind.

There is no doubt the accumulator is an unreliable piece of apparatus when handled by inexperienced persons, both for low- and high-tension systems. The ordinary gas-engine driver and the modern chauffeur cannot usually diagnose a sickly accumulator, or even recommend a cure, and this is one of the reasons why the dry cell should be encouraged. If used and connected in a somewhat similar manner to

that mentioned on page 141, it will give good results. I can advise the use of the dry cell for an ordinary make-and-break contact and plain coil, but with a trembler coil the cell is subjected to heavy duty and is quickly exhausted. A reliable cell can now be obtained with high capacity and reasonable weight. A perfectly balanced coil should not take more than 0·75 ampere with an E.M.F. of 4 volts. Reflashing the magnets is synonymous with remagnetising the permanent magnets. This is more satisfactorily carried out by constructing a large electro-magnet and stroking the poles of the permanent magnet on its face. Remagnetising will probably be required every three or four years. With regard to the type of contact, the one that has a combination of the wipe and the make-and-break is obtainable. The wear is less and you have greater power, due to more even running, as pointed out in the experiment I made and mentioned on page 142. Mr. Warr.

In reply to Mr. Frith, an ordinary form of make-and-break contact on the half-time shaft is used with the hot-wire system of ignition. The resistance is used for causing late or early ignition. The accumulator alone, mentioned on page 135, must, of course, be operated with mechanical tappets. Magnetic tappets are not entirely new, but the system illustrated is new, taking the whole arrangement together, and is likely to meet with great favour. The arrangement is actually in use on the road. With regard to the make-and-break contact experimented with, and mentioned on page 142, this is a combination of the wipe contact and the make-and-break. Briefly, two parallel platinum points are operated by a cam on the half-time shaft placed between two blades, which alternately make and rupture the circuit. The wipe contact usually has a rotary motion, and is shown for four-cylinders in Fig. 1. This type of contact was tried in the experiment, but constructed for two-cylinders. To ascertain the correct position of the contact screw of the trembler blade, the ammeter should be connected up in circuit between the terminal of the two-way switch and the common bar of the coils shown in Fig. 9. The application of the fuse is only required if you do not possess a suitable ammeter, and is to be recommended for setting the trembler blade only. A reversing switch should not in any way impair the running conditions of any motor if the wiring and connections are correctly carried out.

As to retarding the spark when climbing a gradient, if the spark be timed to occur when the piston is just starting on the expansion stroke with the engine stationary, this position of the spark will not be correct when running at high speeds on the level, because the timing is late owing to the lagging magnetic effects of the coil. Whenever a current is applied to a coil there is a short period during which the current is growing to its full value. With the timing set just mentioned, and the engine running at its minimum speed, the spark can be produced as timed. Seeing that the engine speed is lower when mounting a gradient, it is better to retard the spark from the position used at high speed. I cannot agree that it is a mistake to use a single coil for multi-cylinder engines. The advantages of reducing a multiplication of parts is

Mr. Warr. paramount, and the trembler blades are a serious drawback. De Dion and other eminent makers adopt this method with satisfactory results.

No doubt, with the progress of time Sir Oliver Lodge has made several improvements in his "B" spark. A system of this kind must be continually open to improvement. Leyden jars and coils as used in his first investigation could not be conveniently placed in an automobile. To accommodate the essential details in a compact area must have been a problem. I know nothing of the unpublished history of the "Lodge Ignition." From what I can see of it, the principle is closely connected with the many beautiful published experiments of Sir Oliver's in connection with high-frequency lateral and oscillatory discharges.

Operating the timing at the steering pillar cannot be connected with the lagging effects mentioned on pages 143 and 144, any more than operating the throttle lever can hasten the gas into the cylinder. The inevitable lag mentioned by the speaker is due to the interval of time from the application of the current to the production of the spark, and also from the moment the spark appears to the moment at which it fully inflames the volume of compressed gas. It is quite possible to have two firing-points from individual plugs operating at the same time in parallel, with suitably designed plugs and equal gaps. Theoretically, two or more firing-points in one cylinder should improve the running conditions, but whether they do so in practice is dependent on several factors. I agree with the speaker as to earthing the half-time shaft. In multi-cylinder engines, where this shaft has a considerable length of bearing surface, the film of oil between the two surfaces must partially insulate the earthed return circuit.

With reference to Mr. R. B. Slacke's remarks, I have tried the vaseline cup round accumulator terminals. As time goes on the acid spray will damage the terminals in spite of these precautions—at any rate, this is my experience. I have known cases where 2,500 miles have been obtained without the platinum points seriously pitting. The great difficulty seems to be to obtain platinum rivets that do not contain spurious metal. I know in one instance 5,000 miles have been obtained with good platinum in a magneto.

I would like to point out that it is not mechanical characteristics that causes the numerous faults in the coil windings. It must be remembered that the insulation of the secondary winding is subjected to an enormous electrical stress if the two ends of this winding are on open circuit—in other words, if they are not spaced to allow the spark to jump across. The safety-gap, which I mention as an advantage, is analogous to the relief valve of the steam boiler. If steam is not continually taken from a boiler that is near blowing-off point, the relief valve comes into operation. So with the coil: if no safety-gap is provided for the secondary winding of the coil when the connection to the spark-plug is defective or detached, the spark will jump to a point of lower potential somewhere. Usually this takes place inside the coil

windings, finding a point of lower potential in the condenser or primary windings. Mr. Warr.

With reference to the relative advantages and disadvantages of the magneto and coil ignition, considering the matter from a financial point, the magneto is certainly more expensive in initial cost than the coil equipment, but as the mechanism is more simple and compact there is less chance of a breakdown. If a magneto gets a fit of the sulks, it can probably be put right in less time than it would take to find a battery or coil. Further, the magneto is a more reliable article, and defects or faults will be considerably less than with the coil. If this is considered, the renewals with coil ignition are likely to exceed the price of a magneto. There is no doubt greater power is obtained from the magneto than the coil. The reason for this is, of course, that as the speed of the armature increases, the spark produced becomes larger and hotter, and combustion is commenced and progresses more rapidly. With regard to Mr. A. R. Stelling's remarks, I agree that certain advantages are obtained from an oscillating shuttle-wound armature. I see no reason why a secondary winding could not be added to produce a high-tension spark, and thus do away with tappet gears. I have explained fully in another paragraph why I advocate safety spark-gaps on coils, and also with regard to operating sparking plugs in parallel. It is difficult to imagine the use of chemical ignition being satisfactory. Without going very deeply into the matter, I cannot see how an inexhaustible supply of chemical energy could be generated without making things more complicated than they are at present.

In reply to the Chairman's remark, it is difficult to demarcate high- and low-tension current. Usually for ignition purposes the induced current causing a spark to bridge a given gap is considered as high tension as distinct from that derived from a primary source.

SOME EXPERIMENTS ON SINGLE AND STRANDED LOW-TENSION FUSES.

By WILLIAM TOLMÉ MACCALL, Associate Member.

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For a single-wire fuse the usual formula is that due to Sir William Preece, viz. :—

$$C = k \,.\, D^{\frac{3}{2}},$$

where—

C = fusing current in amperes;
D = diameter of wire in inches;
k = constant for any particular metal or alloy,

its value being about 10,244 for copper, 1,642 for tin, and 1,379 for lead.

These constants are proportional to—

$$\sqrt{\frac{T\,E}{P}} \text{ (see Appendix),}$$

where—

T = rise of temperature to fuse the wire.
P = resistivity at temperature of fusion.
E = emissivity at temperature of fusion.

Now T and P are constant for a given material, but it is well known (though not apparently by the suppliers of fuse wire, who generally give Preece's table) that E varies with the size of wire. Consequently, we must either adopt a different formula or alter the "constant" for different sizes. Further, the form, material, and size of the fuse-holder will affect the fusing current.

When we come to stranded fuses, no such simple theory is applicable, because the wires will diminish each other's emissive power to an extent which can be determined only by experiment. All we can predict is that a two-strand fuse will carry less than twice the fusing current of either of its equal wires, and probably more than 1·41 ($\sqrt{2}$) times this current, since its emissive power should be greater than that of a single wire; similarly, for a three-strand fuse, the current will lie between thrice and 1·73 times that of the single wire, and so on.

The objects of these experiments, then, is—

1. To determine the variations in Preece's "constant" (or in the emissive power) with change of diameter.
2. To determine the effect on fusing current of house-service fuse-holders.
3. To find the ratios of the fusing currents of single and stranded fuses in the open and in fuse-holders.

Method of Experimenting.—The normal fusing current for a given wire and environment is the minimum current to fuse the wire when sufficient time has elapsed for it to reach its maximum steady temperature.

This was usually obtained by slowly increasing the current, starting with a current well below the N.F.C., which was allowed to flow for 3 minutes and increasing by 0·1 ampere increments (smaller for the smaller fuses, and larger for the larger stranded fuses), with pauses of 1 minute. Occasionally the alternative method of Schwartz and James * was employed, in which the times taken to blow the fuse with various currents above the N.F.C. are determined and plotted, when the N.F.C. is the current line to which the time-current curve asymptotically approaches.

When a closer approximation was desired this was obtained by making an allowance according to the fraction of the last minute which elapsed before the fuse was blown.

The current was obtained from a battery of Tudor accumulators, seven-plate cells giving 18 amperes on a 10-hour discharge, the number of cells used being varied to suit the current required and a wire rheostat being used for approximate adjustment, with a carbon rheostat for exact adjustment.

The ammeters were calibrated by a Kelvin balance, and the one used for the smaller currents was further checked by a standard low resistance, a standard cell, and a potentiometer.

The diameter of the fuse wires was obtained by weighing a measured length in air and in water.

The wire was then divided up and shorter lengths weighed to test the uniformity of gauge. An example will illustrate this :—

Tin wire 28 S.W.G., nominally 14·8 mils diameter.
Length 3,021 mm.
Weight in air ... = 2·654 grams.
Weight in water = 2·294 "
Difference ... = 0·360 "

$$\therefore \text{ Specific gravity} = \frac{2·654}{0·360} = 7·37.$$

$$\therefore \text{ Area} \quad \ldots \quad \ldots = \frac{0·360}{302·1} \times 100 = 0·1192 \text{ sq. mm.}$$

* *Journal of the Institution of Electrical Engineers*, vol. 41, p. 40, 1908.

$$\therefore \quad \text{Diameter} = \sqrt{\left(\frac{4}{\pi} \times 0{\cdot}1192\right)} = 0{\cdot}389 \text{ mm.}$$
$$= 15{\cdot}3 \text{ mils.}$$

Three separate metres weigh in air—

0·878 grams, 0·883 grams, 0·875 grams.

∴ Variation of diameter from mean value—

$$= \quad -0{\cdot}01 \text{ mils,} \qquad +0{\cdot}035 \text{ mils,} \qquad -0{\cdot}035 \text{ mils.}$$

These variations are so small as to be negligible, and similar results were obtained for the other sizes, the percentage variations never exceeding, and usually being less than, the above.

The earlier experiments were made with the fuse horizontal, as these are the conditions for which Preece's constant is usually stated; it was found, however, that even in air the results were somewhat irregular and considerably affected by vibration, a small amount of this reducing the fusing current by over 5 per cent. in the case

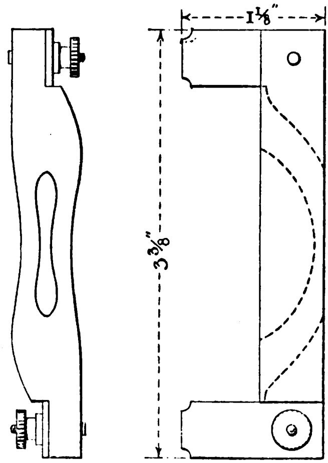


FIG. 1.

of 28 S.W.G. tin wire single strand. When the fuses were in a porcelain holder, the results were high and very erratic, varying in the above case from 7 amperes to 8·3 amperes. Consequently the later experiments were made with the fuse vertical, as is usual in practice.

Trouble was further experienced owing to the cooling effect of varying air currents, and this was surmounted by protecting the fuse by a short wooden board on one side and at right angles to this a

wooden box with a glass cover, the latter facing the fuse, the distance from the fuse being about 2 in. in each case.

For the experiments in air large terminals, $\frac{7}{8}$ in. diameter, with screws 0·44 in. diameter, were employed, with centres placed 3 in. apart. The fuse-holder employed was of porcelain, with copper end-pieces, to which the fuse was attached by nuts and washers (Fig. 2).

The present series of experiments is confined to tin fuses in air and in this one type of fuse-holder, and deals chiefly with single- and two-strand fuses, a few three-strand experiments being made, but insufficient to obtain general conclusions.

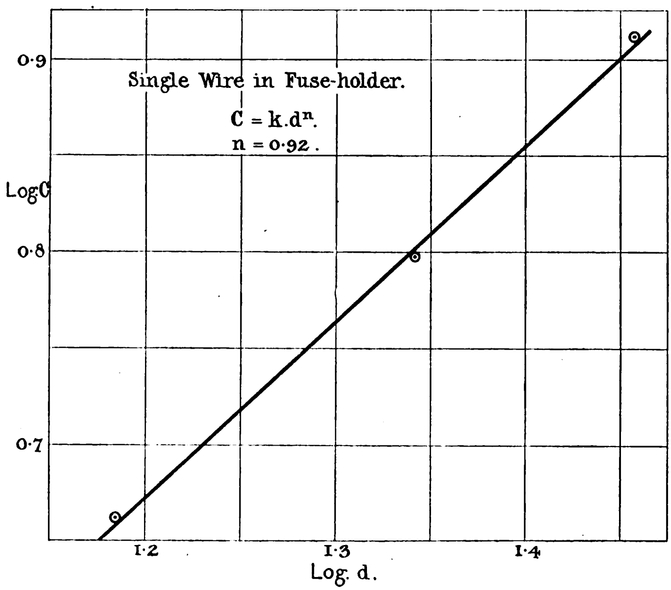


FIG 2.

To allow for variations in air temperature, a standard of 16° C. was adopted and the actual currents multiplied by the following numbers :—

Air temperature	14° C.	15° C.	16° C.	17° C.	18° C.	19° C.	20° C.
Multiplier ...	0·995	0·998	1·000	1·002	1·005	1·007	1·009

This table is derived from the relation that the fusing current—

$$\propto \sqrt{T - t},$$

where—

T = fusing temperature ;
t = air temperature (see Appendix).

These corrections were usually negligible.

Taking Stefan's law the corrections are still smaller, *e.g.*, for 20° C. the multiplier becomes 1·004.

Experimental Results.—The fuse wire contained 99·6 per cent. tin. (For this analysis I am indebted to Mr. Smith, head of the Chemistry Department, Halifax Municipal Technical College.)

The number of experiments made in obtaining each of the results to be given, varied according to the amount by which they differed among themselves; the range is from five to twenty experiments per result. To give an idea of the accuracy in the various cases, the "probable error" is usually stated; this is equal to—

$$0{\cdot}67\sqrt{\frac{d_1^2 + d_2^2 + d_3^2 + \ldots}{n(n-1)}},$$

where d_1, d_2, d_3, etc., are the differences of the observed values from the mean, and—

$$n = \text{number of observations.}$$

SINGLE WIRES.*

(Air temperature 16° C.)

Diameter. Mils.	S.W.G.	In Air or Fuse-holder.	N.F.C. Amperes.	Probable Error.	$10^3 \times$ E.	$k \div 10^3$.
15·3	28	Air	3·58	± 0·05	2·60	1·89
21·9	24	"	5·26	± 0·05	2·42	1·66
28·6	22	"	7·53	± 0·03	1·77	1·56
15·3	28	Holder	4·58	± 0·04	4·27	2·42
21·9	24	"	6·28	± 0·02	3·44	1·94
28·6	22	"	8·17	± 0·02	2·08	1·69

The value for 28 S.W.G. in air is with fuse horizontal, all others with fuse vertical.

The values of E can be calculated either from the actual fusing currents or from the values corrected as above to an air temperature of 16° C.; the results are identical, since the air temperature is taken into account in the calculation (see Appendix). Preece's constant (k) is given for the diameter in inches.

It will further be seen that the values of E and of k decrease with increasing diameter, especially for fuses in holders; in fact, in the latter case the N.F.C., instead of varying as $d^{\frac{3}{2}}$ does not vary even as rapidly as the diameter, but about as its 0·92 power (Fig. 2).

Again, in all cases a wire carries more current before fusing in a holder than the same wire in the air, but the increase is most marked for the smaller wires, the respective increases being 28 per cent., 19 per cent., and 8 per cent.

* Compare Schwartz and James, *Journal of the Institution of Electrical Engineers*, vol. 35, p. 364, 1905.

This is only natural since the holder itself will radiate at about the same rate for each wire, which means a smaller percentage the larger the wire. To test this supposition we may calculate $C_H^2 - C_A^2$ where—

$$C_H = \text{N.F.C. in holder}$$
$$C_A = \text{N.F.C. in air ;}$$

the values obtained are 9·2, 11·8, and 10·0 respectively, a very fair agreement.

Passing on to two-stranded fuses, the question arises as to the effect of more or less twist of the wires. As a first approximation we may consider this to be that the resistance is increased owing to the greater length of wire per centimetre of fuse while the effective surface is not increased. Further experiments are required on this point; those done up to the present give a much greater effect, but are insufficiently complete to be quoted. To avoid complication from this source, the amount of twist in the experiments of which the results are given was kept moderate and approximately proportional to the diameters of the wires.

Two-strand Fuses.

(Air temperature 16° C.)

Diameter Mils.	S.W.G.	Twists per Inch.	In Air or Fuse-holder.	N.F.C. Amperes.	Probable Error.	$10^3 \times E$	$\frac{k}{10^3}$
15·3	28	3¾	Air	5·37	±0·03	1·47	1·42
21·9	24	3	”	8·85	±0·06	1·37	1·37
28·6	22	2	”	13·0	—	1·32	1·34
15·3	28	3½	Holder	6·37	±0·04	2·06	1·68
21·9	24	2¾	”	9·33	±0·07	1·53	1·44
28·6	22	2½	”	13·4	—	1·41	1·39

The same general results are seen here as for the single fuses except that *k* varies less especially in air, probably because the results for 28 S.W.G. are less affected by its being placed horizontal than they are in the case of single wires. The increase in N.F.C. when fuse is placed in holder are 19 per cent., 5 per cent., and 3 per cent. respectively, again showing a diminishing effect with increasing size, and smaller effects than for the single wires. These are both due to the same cause already stated—viz., the radiating power of the holder being fixed, for again calculating $C_H^2 - C_A^2$ we obtain 11·7, 9·7, and 10·6, which agree among themselves and with the values for single wires.

Comparing the two sets of results we obtain the following :—

RATIO OF N.F.C.'S FOR SINGLE AND DOUBLE FUSES.

S.W.G.	In Air or Fuse-holder.	$\frac{\text{N.F.C. for Two-strand.}}{\text{N.F.C. for Single.}}$
28	Air	1·50
24	"	1·68
22	"	1·73
28	Holder	1·39
24	"	1·49
22	"	1·64

The first figure is affected by the position of fuse being horizontal, so that probably the ratio is fairly constant in air. Some experiments on 29 S.W.G. gave a ratio of 1·62, but owing to the conditions being somewhat different the separate figures are not given. The increasing values with increasing diameter for wires in the holder are due again to the diminishing effect of the holder, so that these values gradually approximate to those for fuses in air.

A few experiments were made on three-strand fuses which give a N.F.C. of a little over twice that of single wires of the same size. It is hoped to complete these and to extend the results to fuses of other materials.

APPENDIX.

THEORY OF FUSES.

Let—

C = Normal fusing current in amperes.
P = Resistivity of material at fusing temperature in ohms per centimetre cube.
D = Diameter of fuse in centimetres.
d = Diameter of fuse in mils.
T = Fusing temperature in °C.
t = Air temperature in °C.
E = Emissivity in calories per sec. per sq. cm. per °C. excess of temperature.

Then—

$$D = 0·00254\, d.$$

The heat produced per centimetre length per second—

$$= \frac{C^2 P}{\frac{\pi}{4} . D^2}$$

The heat emitted per centimetre length per second—

$$= \left(T - t\right) \pi \text{ D E calories}$$
$$= J \left(T - t\right) \pi \text{ D E joules.}$$

Under steady conditions these are equal, whence—

$$E = \frac{4 C^2 P}{\pi^2 J D^3 (T - t)}$$

For tin—

$T = 230° C.$
$P = 26{\cdot}4$ microhms per cm. cube.

$\therefore$ Taking $J = 4{\cdot}19$ and expressing diameter in mils we have—

$$E = \frac{156 C^2}{d^3 (230 - t)}$$

For two strands the area of cross-section is doubled, and the surface is doubled if we take the cross-section as consisting of two circles touching only at a point.

Hence—

$$E = \frac{39{\cdot}0 C^2}{d^3 (230 - t)}$$

where $d =$ diameter of each wire in mils.

Similarly for three strands the area of cross-section is trebled and the surface is $2\frac{1}{2}$ times that of a single wire, taking it as that of three circles each touching the other two.

Hence—

$$E = \frac{10{\cdot}8 C^2}{d^3 (230 - t)} \quad (d \text{ as above}).$$

The above assumes Newton's law of cooling: if, however, Stefan's law be taken, viz. :—

Radiation $= M (\Theta^4 - \theta^4)$ calories per second per sq. cm.

where—

Θ = absolute temperature of fuse ;
θ = absolute temperature of air ;
M = a constant for any particular body ;

then, for an air temperature of 16° C. and a tin fuse melting at 230° C. = 503° C. absolute—

$$\frac{M}{E} = \frac{230 - 16}{503^4 - 299^4} = 3{\cdot}8 \times 10^{-11},$$

the values of E being those given in the paper.

Further, according to this law E varies with the temperature, and the values given are mean values of a sort, corresponding with the value at 131° C. To obtain the value at 16° C., the factor $230 - t$ (= 214) in the expression for E must be replaced by $\frac{503^4 - 299^4}{300^4 - 299^4}$ (= 526), *i.e.*, the given values must be multiplied by 0·41. Similarly the value at the mean temperature of fuse and air, viz., 123° C., can be obtained by multiplying the stated values by 0·95.

Discussion.

Mr. Cridge. Mr. A. J. Cridge: There is much in this paper, but one cannot read it without thinking how much more of the subject remains to be dealt with. The author admits that he has realised this, and says that further experiments are necessary, especially with regard to different numbers of strands and the amount of twisting. It has occurred to me during the reading of the paper that the effect of twisting may be to some extent estimated. If there are two equal wires, which are not twisted together at all, the cross-sectional area of the fuse is twice the area of a single strand, and the surface is twice as great. If the wires are twisted as tightly as possible, the fusing current appears, using Sir William Preece's rule, to be $\sqrt{8}$ times the fusing current of the single wire. When we begin to twist wires together the area varies because the cross-section becomes elliptical.

Many people deal with fuses, and there are some among them who are not, I am afraid, as familiar with the proper way of treating them as they might be. I have known men who, not having the gauge of fuse-wire required, have taken a piece of wire of larger gauge, and reduced its cross-section by stretching. Of course, this is a most inaccurate and erroneous way of trying to arrive at the required result. Experiments such as Mr. Maccall's are valuable, and I hope he will go on with them, and, at some future time, give us the benefit of his researches.

Mr. Yerbury. Mr. H. E. Yerbury: The author's experimental work on fuses and their behaviour under certain conditions is valuable, even if the results obtained are not often made use of in actual practice. It appears to me that if one must allow such a large factor of safety in all fuses used for domestic and industrial purposes, the difference in fusing-point with different types of holders and in air would probably be ignored by practical men. It is certainly undesirable in general practice to work to a very fine margin between safe carrying capacity and fusing-point, but for certain fine work the result of the author's researches,

especially in respect to the value of the constant k, will undoubtedly prove useful. Mr. Yerbury.

Mr. E. J. MARSH : I should like to ask the author what would be the effect of switching on and off repeatedly, what is the maximum observed fusing current for a wire, and if the result would give a higher carrying capacity ; also what result would be obtained if two similar fuses were placed in series, one in air and the other enclosed in a holder on a short circuit, and would the fuse in air blow first? The long period given in the experiments in the paper allows plenty of time for the heat to dissipate, but in the event of a short circuit the interval would not allow of this. Would the fuses in this case act simultaneously? I should be glad to know if the author has carried out any experiments with cartridge fuses, and if the readings are similar, owing to the closeness of the wire to the radiating material to those given for the fuse-holders. As these fuses are in general use it would be of considerable interest to have some information respecting them. Mr. Marsh.

Mr. T. W. SAMPSON : With respect to the effect of the holder on the fuse, this is a very interesting point. It seems contrary to what one would expect to find that the fuse-holder has practically a constant value in reference to its effect on the fusing current. This is strange, because one would think that with a small wire raised to a high temperature the heat is comparatively slight, and it would raise the temperature of the fuse-holder only a comparatively small degree. Seeing that the emissivity of the fuse-holder depends on the temperature to which it is raised, one would think that with a larger fuse it would be raised to a higher temperature because of the greater amount of heat produced, and therefore with a larger fuse the fuse-holder would not have as much effect as with a small one, and that seems to be borne out in some respects by the values given. For instance, taking the values given of 7·53 and 8·17, the difference is less than in the other cases, and it seems strange that the constant so calculated comes out at approximately the same. Mr. Sampson.

The value of k in Preece's formula might naturally be expected to alter somewhat because it depends on the diameter of the wire, but the emissivity depends on the circumference of the radiating surface. The carrying capacity goes up as the square of the diameter, but the radiating surface is only proportional to the diameter itself, and hence the fusing current goes up as the square of the diameter. The surface from which heat can radiate varies only as the diameter itself, and from that point of view one would therefore expect that the value of k would alter somewhat with the different diameter of wire.

Regarding the twisting effect, we are told that the capacity of the twisted fuse is less than twice that of a single fuse, which cannot altogether be accounted for by extra length. With the extra length of wire due to the twist one would expect that to be the case because there is not twice the amount of radiating surface when the wires are twisted as when they are straight, therefore there will be a greater

Mr. Sampson. length and less radiating surface, which will have the effect of reducing the fusing current.

Mr. Walker. Mr. F. M. WALKER: I should like to know why the author used a carbon rheostat for getting exact adjustment. I should have thought that the resistance decreasing with the heat would have made it rather likely to vary.

Mr. Wardrobe. Mr. F. WARDROBE: About twelve months ago I made a number of experiments on fuse wire in a rather rough-and-ready fashion. We had a variable resistance and an ammeter, and took three critical points in the fuse load, these being at the first sign of heating, when red hot, and at the melting-point. The first sign of heating gave the maximum working load and the red-hot stage the average safe overload. These readings were taken several times for each size of wire and an average was struck. There was nothing particularly scientific about the tests, and I had never connected them together by any formula. They were simply made for the purpose of standardising a particular make of fuse wire used in standard fuse carriers. I find, however, that the relation of single-strand to two strands pretty well agrees with that given by the author, while with three strands over two the ratio comes out about 1·37, and four over three about 1·2. These fuses have now been standardised all over the works and their use has been attended with very good results.

There are two or three different types of holders in use, but most of them are of the porcelain or hardwood tubular type with a lining of hard asbestos tube. The loads range from 20 to 450 amperes, so that an ampere either way in the fusing-point of the wire does not make much difference. Copper is used throughout, and I find it very constant in working. I do not believe very much in cartridge fuses for works loads, as they are rather expensive and troublesome to renew, whereas it is a very quick job to renew the wire in an open type of fuse. The wires are not twisted, but put in side by side, when two or more strands are used.

Mr. James. Mr. W. H. L. JAMES (*communicated*): Having devoted some considerable time to research work on fuses, I am pleased to have the opportunity of assisting in the discussion of the work of a fellow experimenter. I notice that Mr. Maccall's experiments on single wires confirm the results given by Professor Schwartz and myself* as to the considerable and variable departures from Preece's law ($n = 1{\cdot}5$) which occur in practice.

I am of opinion that Mr. Maccall has been rather unfortunate in his choice of fuse-holder. In the type used, even if the wire is quite tight when put in, it will expand slightly before fusion and the degree of contact between the cooling porcelain surface, and the fuse-holder will be of a variable and uncertain nature.

A fuse-holder in which the wire was either definitely in contact or definitely out of contact at the moment of fusion would, I think, have been more satisfactory.

* *Journal of the Institution of Electrical Engineers*, vol. 35, p. 364, 1905.

At the bottom of page 166, Mr. Maccall states, "In all cases a wire carries more current before fusing in a holder than the same wire in air." This though true for the type of holder made use of, is not true for every type of fuse-holder. Mr. James.

If a tubular fuse-holder is used with the wire going down the centre (out of contact with the porcelain) the normal fusing current may be lower in the fuse-holder than in the open air.*

Mr. W. M. ROGERSON: I feel, like Mr. Cridge, that the paper would have been a little more valuable if the author had been able to give a few more results. As he says in his paper, his experiments, at any rate on three strands, are not sufficiently accurate to justify any conclusions. I hope that he will be able to make experiments not only on tin wire, but also upon copper, and more especially on aluminium. From my own experience I find that aluminium as a fuse gives far better results in the case of heavy currents, there being less than half the sparking or explosion that there is with tin or copper, and the part melted is confided to a very small area. With a fuse 6 in. long copper will practically fuse for the whole length of the wire, and if in an iron case with a dead short, it will probably take half the case with it, but with aluminium the explosion is confined practically to the wire itself; in my opinion aluminium is one of the best metals you can possibly use for fuses. In Halifax we have adopted aluminium altogether with excellent results. Mr. Rogerson.

Mr. W. T. MACCALL (*in reply*): With regard to Mr. Cridge's remarks respecting the twisting of the strands, even if there is no twist there will still be a reduction in fusing capacity. Mr. Wardrobe's results, I believe, were without twisting. The only way is to put the wires so far apart as not to interfere with radiation. With the wires at any ordinary distance apart there will still be a reduction in the amount of the current. The case mentioned of twisting one wire completely round the other does not quite agree with what is actually done. In practice the wires are both twisted. I have not worked out that particular case, but I think it was worked out for the case of one wire straight and one twisted round it. The effect of twisting Mr. Sampson thinks should naturally be a reduction of fusing current due to increasing the resistance. That may or may not be the case, because when two wires which are just straight and touching are compared with the same two wires twisted together, it might be expected that there would be little change owing to increase of resistance in the wires being accompanied by an increase of surface, and one might expect the latter to increase the fusing current. I think it is necessary to make an experiment in order to see what really happens. As far as I have gone the effect is greater than if we take it as due only to the increase of the resistance, but how much greater I could not say; perhaps it may be four times as much. Mr. Maccall.

Mr. Yerbury said it was necessary to work to a high factor of safety,

* *Journal of the Institution of Electrical Engineers*, vol. 35, p. 384, 1905.

Mr. Maccall. and the differences were too small to matter. I quite agree that that is so for larger wires, but I think for wires of small diameter, *e.g.*, 28 S.W.G., which is often used, having a fusing current of 3 or 4 amperes, and even for 24 S.W.G., the difference produced by placing that wire in the holder is sufficiently important to matter, especially as it is an increase. This type of holder increases the fusing current, and consequently more current goes through than has been estimated. Although there must be a factor of safety, it is as well to know what the factor of safety is. Mr. Marsh inquired as to the effect of switching the current on and off quickly. If the normal fusing current be switched on and off quickly the wire would certainly not fuse, because it would cool down in the intervals.

Mr. Marsh also put the question differently: Suppose there were two similar wires, one in a holder and one in air, and they were short-circuited, which one would go first? The experiments given in the paper were done on normal fusing currents and not on short circuits. Professor Schwartz and Mr. James in their paper dealt with the latter question. The normal fusing current is that which will just fuse the wire if left long enough. I have not done any experiments on short circuits, but I imagine that the difference in fusing current would be sufficient to make the one in air fuse first. There is this further point that the time it takes to warm up the wire is much less in air; and because of the requirements of heating the holder up as well as heating the wire on a sudden short circuit, the difference would be sufficient to make the one in air go first. The difference may not be as large as that for steady currents, but there would be some difference.

Mr. Sampson said he was surprised that the effect of the holder should be constant, but thought that with a bigger wire, owing to the greater quantity of heat, the effect would be different. I do not quite agree with that, because the size of the wire is comparatively small compared with the size of the holder itself, and since the temperature at which the wire fuses is the same whatever the size of wire used, therefore when the wire is in contact with the porcelain there is at that point a certain definite temperature, and if it be left long enough the heat will distribute itself in exactly the same way whatever the size of wire used. There would be more radiation from the bigger wire, but not from the holder itself.

Further, he stated the results seemed to show that this was so, because with the big wire there was a smaller difference between the currents. That is true, but the same increase occurs in the amount of heat produced. If 7·53 be taken from 8·17, there is only a very small increase by putting the 22 S.W.G. wire into the holder. But if the difference between the amounts of heat produced in that case and the difference between the amounts of heat produced in the other cases be compared, the results are practically the same. The difference between the squares of the two currents is practically the same—that is to say, the heat radiated by the holder is the same for any size of wire. The

Mr. Maccall.

ratio of surface to area is taken into account in calculating Preece's formula. The formula says that the fusing current $C = KD^{\frac{3}{2}}$, not KD^2, so that the increase of surface being only proportional to d, while the increase of area is proportional to d^2 does not explain why k diminishes.

Mr. Walker asked why I used a carbon rheostat. As a matter of fact, it just happened to be convenient, because I had not a continuously variable wire rheostat by me. I agree that there is a certain amount of trouble from the variation of resistance, and care must be taken that the current keeps constant. The wire rheostat would certainly have been preferable. The greater part of the resistance in circuit was wire, and therefore the variation was only small because the carbon rheostat forms a comparatively small proportion of the total resistance.

I was very much interested in Mr. James's criticism that the type of fuse-holder was bad, in that if the wire were quite tight when put in it would expand slightly before fusion, and the degree of contact between the cooling porcelain surface and the fuse-holder will be of a variable and uncertain nature. I had noticed myself that if the fuse were carelessly put in, so that the contact was bad, the current was altered, and it would make quite a considerable change in the fusing current if put in loosely instead of tightly. I think that might also partially explain the difference between the fuse being vertical and horizontal. I think that vertically the contact is fairly uniform so long as care is taken to put the wire in tightly to begin with, for if it sags down with the fuse vertical there is sure to be contact. As the fuse wire comes through it must be in contact somewhere, and although the contact may vary somewhat, I think in the actual experiments that the effect was not very great. It is possible, however, that there is something in it. Mr. James's criticism regarding the statement at the bottom of page 166 is quite correct, but I think it is due to an ambiguous statement on my part. I did not mean to say "in all possible cases" a wire carries more current before fusing in a holder than the same wire in air, but in all the cases dealt with in the table. "In all the above cases" would perhaps have made it clearer. Of course, I know that if a wire be placed in a tubular holder so as not to be in contact with the holder, the fusing current may be diminished and not increased, because there is less cooling effect from a porcelain holder, and the temperature will be raised to a certain extent because the air cannot get away freely from the fuse.

I was glad to hear the results of Mr. Wardrobe's experiments. He mentioned that with two strands he got similar results to those mentioned in the paper. That is interesting, inasmuch as his experiments were done on much larger currents. I was simply dealing with the current one gets in house circuits, and his went up to 600 amperes. I stated the results with three strands compared with single wires, the three strands giving about twice as much as the single wire. His figures of 1·37 times as much with three as with two fairly well agrees with my results. On the assumption that three carries a little more than twice as much as one, and that a double carries 1·5 times as much as a

Mr Maccall. single, the same results are arrived at. I have not done any experiments with four strands, and I am glad to know what to expect. One reason why I have not given any results for the three strands is that in twisting the wires together it is rather difficult to ensure a fairly uniform twist in the three wires. Since the effect of the twist is considerable, it is advisable to make sure that it is uniform. That was one of the troubles in the three-strand experiments which prevented their completion. The reason why I did the experiments with twisted wires was because most people twist them when they put them in. They generally not only twist them, but twist them very hard together. I have not made any experiments with cartridge fuses because I had not time.

With reference to the chairman's remarks, I might say that I realise fully how incomplete the results are, and I hope to do some experiments on three and more strands, and also on copper and aluminium. I had thought that I should get some results on copper in time for the paper, but I could not manage it.

ON THE USE OF THE FLICKER PHOTOMETER FOR DIFFERENTLY COLOURED LIGHTS.

By H. MORRIS-AIREY, M.Sc., F.R.A.S.*

(*Paper received from the* NEWCASTLE LOCAL SECTION, *November* 11, *and read at Newcastle on December* 6, 1909.)

In recent years photometers of the flicker type have obtained a certain degree of prominence, and it is claimed for them that they enable the illuminating powers of sources of light of distinctly different colour to be compared with one another with an accuracy unattainable by means of photometers of the steady illumination type.

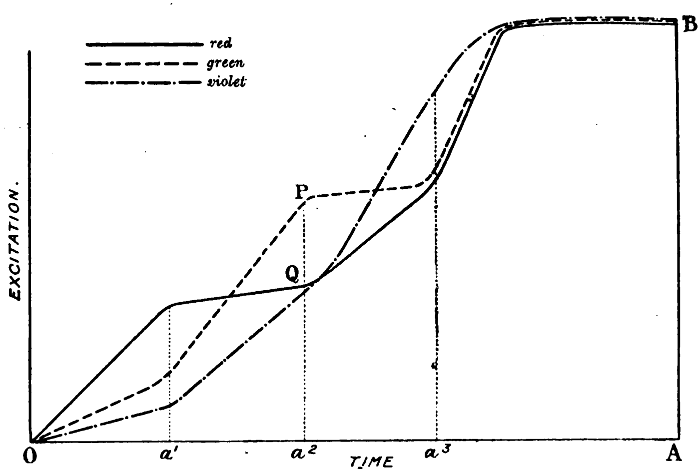
From time to time, however, suspicions have been raised as to whether the principle on which the flicker photometers are based does not involve physiological phenomena which disturb the conditions of illumination so that the numbers obtained are not a true representation of the illuminating powers of the sources to be compared. The exact *rôle* which the speed of rotation of the flicker head plays in the experiment is especially doubtful, while physiological evidence indicates that the effect is a very complicated one, and the simple theory of the flicker effect is not tenable.

The problem as to what actually happens in the retina when it is stimulated by steady or intermittent light is, of course, a physiological one, and in seeking for some generally accepted facts with regard to colour vision, we are met with the difficulty that the most eminent physiologists are hopelessly at variance. The physicist is accustomed to accept in a general way the Young-Helmholtz theory of three-colour vision, and the simplest physiological experiments seem to demand that the percipient structure of the retina involves two kinds of sensitive elements—the rods and cones. The rods are found in greatest numbers in the peripheral region together with a few cones, while in the small central region of clearest vision, the forea centralis, the cones alone are present, the intermediate zone containing rods and cones intermingled.

The function of the rods is to perceive light of intensity insufficient to stimulate the cones, but they appear to be of a primitive type of sense organ, being capable only of one kind of sensation whatever the colour of the light falling on them. The cones on the other hand enable us to see in light which is bright enough to keep the rods in state of exhaustion. They have also the property of differentiating the various colours, the Young-Helmholtz theory assuming that they are of three

kinds specially sensitive to red, green, and violet respectively, any other colour being capable of being represented as a combination of these in suitable proportions. These assumptions enable one to explain many of the striking phenomena of colour vision such as the Purkinje Effect,* though recently doubts have been raised † as to their validity, and it is certainly significant that many of these effects (including the Purkinje Effect) have close analogies in the behaviour of a photographic plate towards coloured light. In this case a structure similar to that assumed for the retina seems excluded.

With every new theory of colour vision the physicist would have to change his starting-point in the explanation of phenomena like the flicker effect, and I suggest ‡ that a more stable foundation for a



physical theory is to be found in the experimental examination of the growth and decay of the retinal stimulus due to differently coloured lights, without any attempt to connect the form of the curves obtained with physiological theories which are admittedly of uncertain stability. The work of G. N. Stewart § appears to afford us the necessary data. In reference to Talbot's law of the fusion of intermittent light stimuli, Stewart found that on observing the flashes of light reflected from a rotating mirror placed in a darkened room, a series of colour changes in the appearance of the image of the source took place as the speed of the mirror was altered. These changes take place at or under the speed necessary for the complete steady fusion of the flashes. The results are shown in the figure above.

* J. S. Dow, *Philosophical Magazine*, vol. 12, p. 120, 1906.
† E. Green, *Optical Society*, October, 1909.
‡ *Electrician*, vol. 63, p. 758, 1909.
§ G. N. Stewart, *Proceedings of the Royal Society of Edinburgh*, 1888.

The three curves represent the growth of the stimulus for red, green, and violet light. The time during which the light acts is measured horizontally, whilst the intensity of the excitation is given by the ordinates of the respective curves.

For a white light stimulus of long duration O A, the excitation of all three colours is equal, giving the sensation of white light. For stimuli of shorter duration, $O\,a_3$, $O\,a_2$, $O\,a_1$, the violet, green, and red excitations are predominant. The succession of colours in "after-images" as described by Helmholtz, Fechner, and others, is consistent with the assumption that the decay of the excitation follows a similar set of curves.

When the light stimulus consists of a series of short illuminations, we may therefore have different predominant tints according to the length of the stimulus and its frequency.

As these colours are observed with intermittent light when the frequency is about or under that required for complete fusion (*i.e.*, disappearance of the flicker), it seems difficult to avoid the conclusion that they will play an important part in the appearance of a flicker photometer head when used for comparing different colours.

Suppose we have adjusted the sources and speed of rotation so that the flicker has just disappeared and we have a balance. The flashes from either source considered independently evidently occur at a rate such that the excitation is not fully developed. If, for example, we were comparing a red and a green source and the duration of each illumination corresponded to $O\,a_2$, the effects *actually* being compared would be a red light of intensity $\frac{Q\,a_2}{A\,B}$ times the real intensity and a green light whose intensity had been reduced by the ratio $\frac{P\,a_2}{A\,B}$, and though the appearance seen by the eye might be a steady illumination whose colour was that produced by mixing red and green light together, this can hardly be interpreted to mean that the actual brightness of illuminations at the flicker head has been adjusted to be the same. If the speed of the flicker head is altered, we shift the position of the ordinate we are considering, and shall then have to readjust the positions of the sources to regain the balance.

The same thing will apply when the sources are not pure red and pure green, but differently tinted lights, such as a carbon filament and a metal filament lamp, and this in practice leads to the results observed by Lauriol,* Wild,† and others.

Whatever may be the ultimate physiological explanation of the working of the flicker, I think the above discussion shows that the conditions under which the retina is excited during a measurement with the flicker type of photometer are not the practical conditions of illumination to which it is our object to apply the data we obtain from the experiment.

* *Bulletin de la Société Internationale des Electriciens*, vol, 4, p. 647, 1904.

† *Electrician*, vol. 63, p. 540, 1909.

Discussion.

Dr. Stroud. Dr. H. Stroud : I desire to thank Mr. Airey for his very interesting paper. He has shown that the flicker photometer, which has been regarded as getting over the colour difficulty, is unreliable on the basis of experimental results. The conclusion to be drawn, I think, from various experiments of recent years throwing doubt on the flicker method is that photometer work is only satisfactory when the lights compared are of the same, or nearly the same, colour.

Professor Thornton. Professor W. M. Thornton : There is no doubt that after this most convincing demonstration the flicker photometer "goes under"; the only question is as to the amount of error. It was brought out to obviate colour effects, but the question of time of establishing colour sensation does not seem to have been considered. Comparing lights of the same colour it is very sensitive. I should like to know what error one might expect in the comparison of metal and carbon filament lamps, and against which of them it tells. A photographic plate is not satisfactory as a standard detector of balance, for it shows inequality when the eye gives balance on a Lumner-Brodhun photometer.

Mr. Holmes. Mr. J. H. Holmes : I should like Mr. Airey to give me an idea of the value in seconds of the line O A in the curve presented in the diagram. The importance of a photometer which will compare different coloured lights is very great. The flame arc lamps now used seem very bright, and it would be interesting to know how one can compare a light of this sort with an ordinary arc light.

Mr. Proctor. Mr. Faraday Proctor : I may mention that I have found it somewhat difficult to get consistent readings between metallic filament and carbon filament lamps. Girls can read on the photometer very accurately with the same coloured lights, but if a metallic filament be put against a carbon filament their readings do not always agree, owing to individual variation in estimates of colour differences.

Mr. Morris-Airey. Mr. Morris-Airey (*in reply*) : With regard to Dr. Thornton's question as to the error to be expected with a flicker photometer, there is no accurate substitute for it, and I doubt if there is such a thing as the comparing of the intensities of two lights of different colour. As regards the difference in results obtained with the flicker photometer and the steady illumination type, there has been found to be as much as 25 per cent. in the estimate when the two lights differed in colour to the same extent as a metallic filament lamp and a carbon filament lamp. As regards the experiment where the photographic plate was substituted for the eye, I think the photographic plate is worse than the eye for observing colour effects.

In reply to Mr. J. H. Holmes' question regarding the length in time of the interval O A, it comes out at about $\frac{1}{40}$ of a second for bright lights and greater for faint lights, but this is only a rough estimate,

RESEARCH ON METALLIC FILAMENT LAMPS.

By F. H. REAKES LAVENDER, M.Sc., Student.

(*Abstract of Paper received from the* BIRMINGHAM LOCAL SECTION, *October* 7, *and read at Birmingham on December* 1, 1909.)

This research was undertaken in order to investigate the conditions of working as regards voltage, and efficiency and percentage drop in candle-power, giving the most economical life in the case of metallic filament glow lamps, and to determine as far as possible the cost of illumination with this source of light.

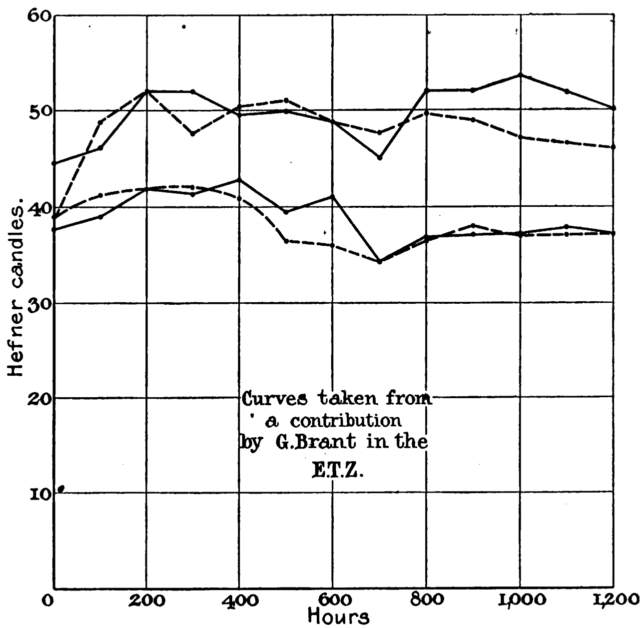


FIG. 1.

It was considered desirable that the results should apply to metallic filament lamps generally, and not to a special make. For this reason a number of lamps were obtained from six firms which were considered

fairly representative of that industry in this country. The lamps were obtained direct from the makers of 100 volts and 25 c.p. They had clear bulbs, and in most cases were marked to burn in any position. Six

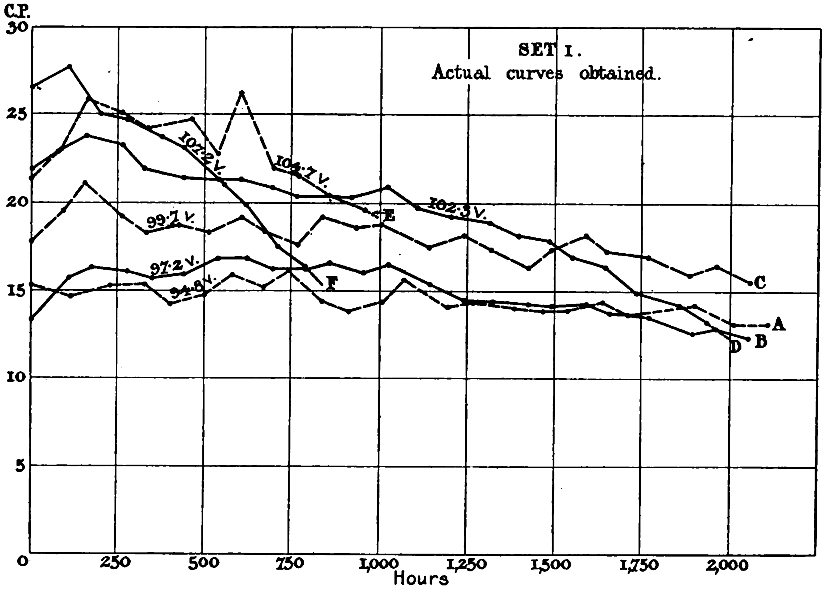


FIG. 2.

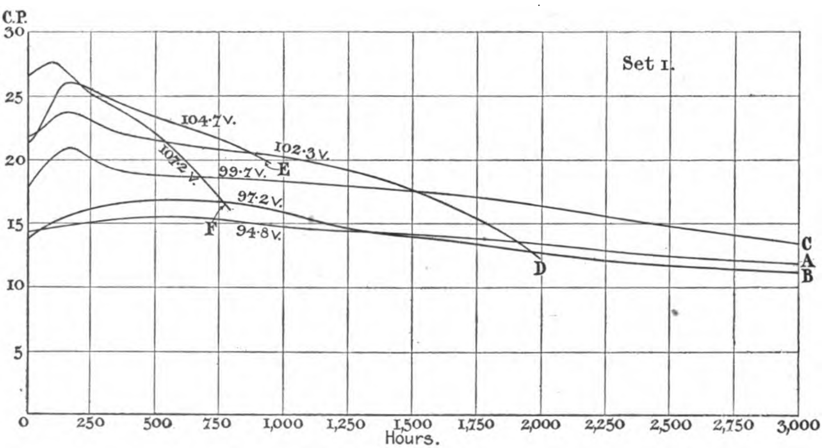


FIG. 3.

lamps of each kind were taken and run at six different voltages, namely, 95, 97·5, 100, 102·5, 105, and 107·5 volts. Thus there were six lamps at each voltage.

For the life tests the lamps were run continuously night and day, week ends included. In the daytime (about 7 hours) power was obtained from the University power station off the 110-volt lighting mains. At other times the load was switched over on to the 220-volt battery,

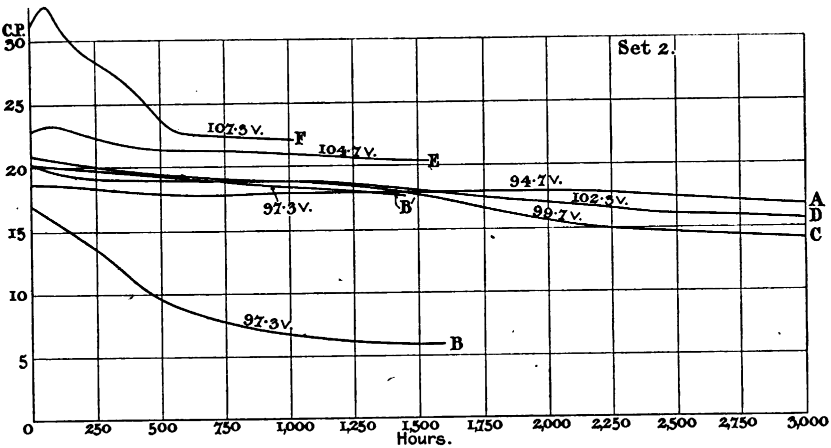


FIG. 4.

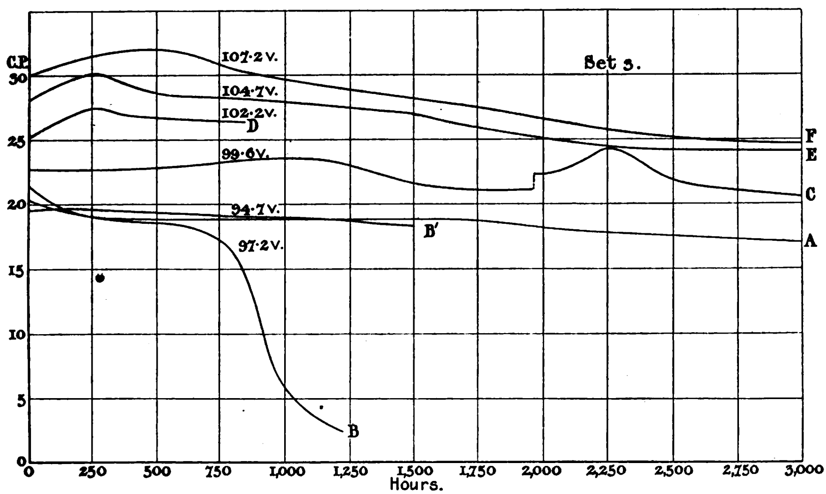


FIG. 5.

which was split for this purpose, half the lamps being on either side. Carbon balancing lamps were used to make the discharge from the battery even. The lamps were run as far as possible under the usual commercial conditions. No special automatic voltage regulation was

used. The drop across the battery during the night was very small, and easily allowed for by slightly increasing the potential difference at the lamp terminals at start. In the daytime the voltage had a limit of variation of 2 per cent. up and down for the most part.

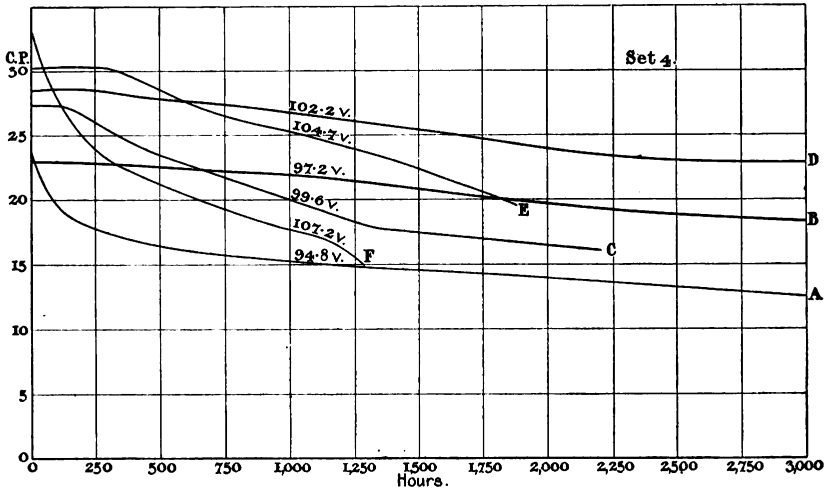


FIG. 6.

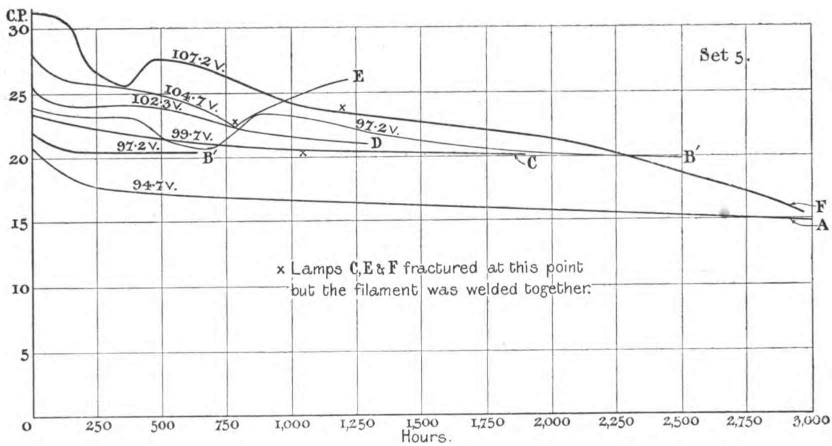


FIG. 7.

The lamps were taken out of their holders and into an adjoining room to be photometered twice a week. Their horizontal candle power was measured on a Bunsen grease spot photometer having a scale of 400 cms. The readings were repeated three times to ensure

accuracy. The standard used was a new 100-volt 16-c.p. Fleming carbon standard, while a 100-volt 25-c.p. Osram was used for a sub-standard.

For convenience a number has been assigned to each make of lamp, the voltage being indicated by a letter as follows :—

Makes 1, 2, 3, 4, 5, 6.

Voltage	A	means	95	volts.
"	B	"	97·5	"
"	C	"	100·0	"
"	D	"	102·5	"
"	E	"	105·0	"
"	F	"	107·5	"

Thus lamp No. 1 A is the one of make A′, run at 95 volts. Those of Set 1 are tantalum, the others are tungsten.

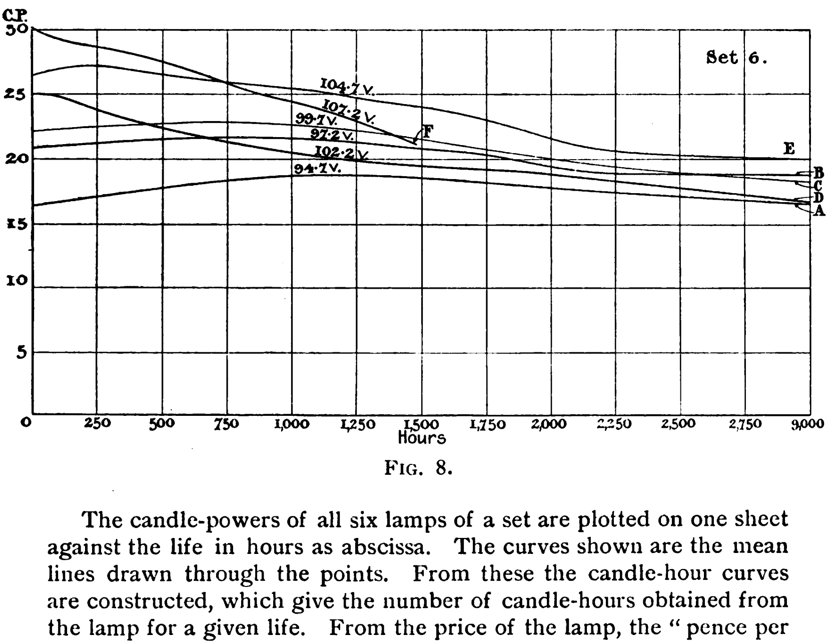


FIG. 8.

The candle-powers of all six lamps of a set are plotted on one sheet against the life in hours as abscissa. The curves shown are the mean lines drawn through the points. From these the candle-hour curves are constructed, which give the number of candle-hours obtained from the lamp for a given life. From the price of the lamp, the "pence per candle-hour" curve is constructed. This, of course, falls rapidly at first, being inversely proportional to the number of hours the lamp has run. It shows the proportion of the total cost which is due to the outlay on the lamp. These curves have been worked out on the latest list prices at the time of writing, which are as follows : Make No. 1, 2s. 6d. ; the other makes, 3s. 6d. each.

On these same sheets the consumption curves corresponding to the lamps are plotted. From these the watt-hour curves are obtained. The watt-hour curve, together with the candle-hour curve

give the curve of $\frac{\text{watt-hours}}{\text{candle-hours}}$. This gives the average efficiency, and, therefore, with a certain price of current, the cost per candle-hour for any pre-determined length of life. Now from this curve together with that of lamp cost the "total pence per candle-hour" curves are plotted. This has been done for current at 2d., 4d., 6d., and 8d. per unit. It was found best to plot them at four different scales, otherwise those at cheaper current would be unduly flat. The scales, however, have been marked on the sheets. When the lamp has been burning a sufficiently long time the ordinates to these curves reach

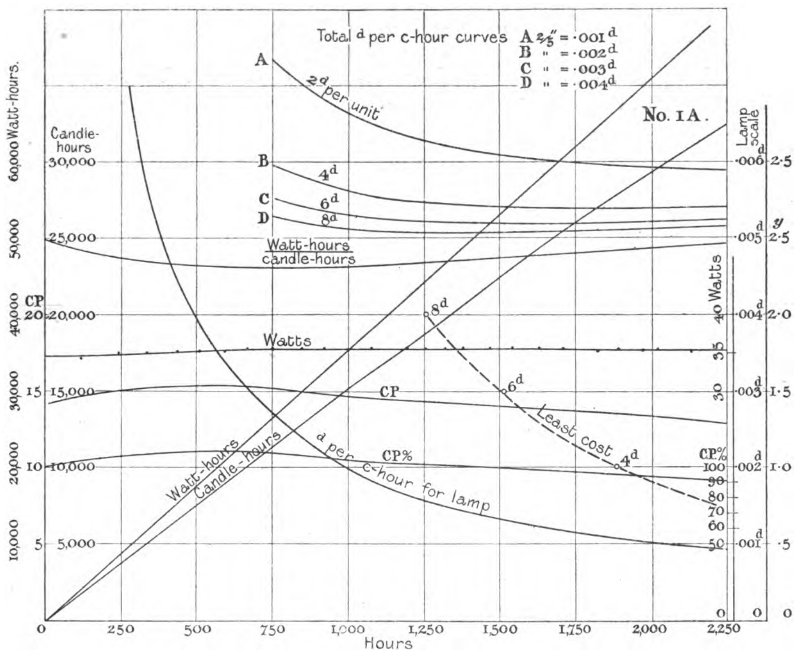


FIG. 9.

a minimum value. This at once gives us the most economical life for the lamp. It happens in some cases that the lamp breaks before this point is reached. However, its absolute life may often be prolonged by welding the filament together, which is easily done by carefully shaking the lamps until the loose end comes in contact with another part, so closing the circuit. This means that it will be overrun to an extent depending on the length of the filament cut out. This is an advantage since, even if the lamp does not last very long, yet for that period we are obtaining light at a higher efficiency and without any cost for the lamp, because it is a "scrapped" one we are using.

For example, lamps Nos. 5 C, 5 E, and 5 F, fractured at 600, 800, and

1,200 hours respectively, and after being joined again burnt to 1,800, 1,200, and 2,900 hours respectively. In other cases the increase in life was not so great. Naturally much greater care has to be taken in handling such lamps, as the joint is very liable to become broken again. This, however, shows that the fragility of metallic filament lamps is to some extent balanced by the possibility of mending broken ones. This does not apply to tantalum filaments, which I understand speedily

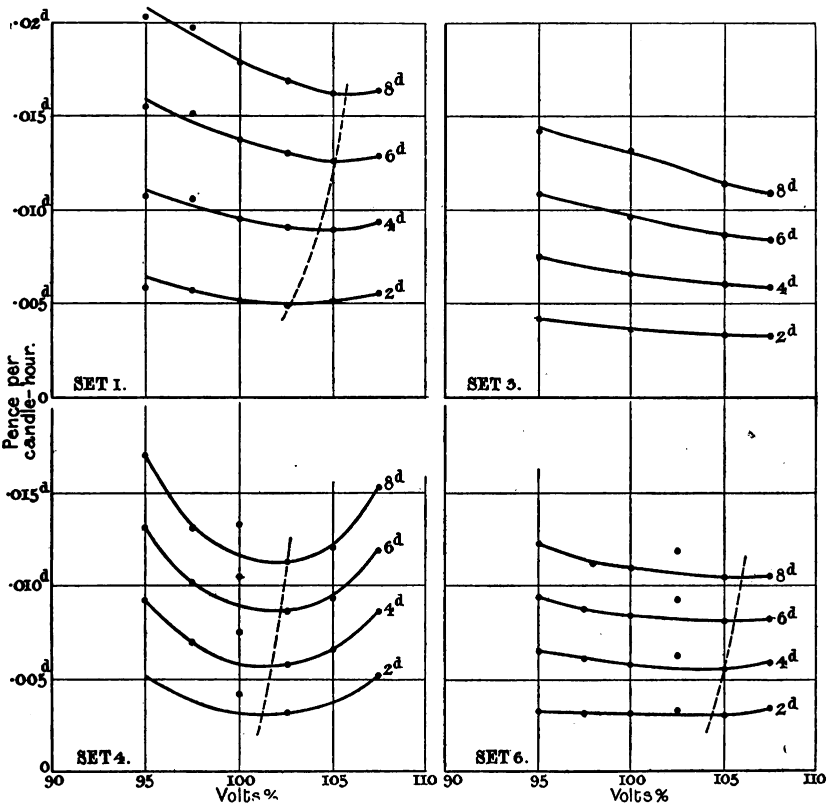


FIG. 10.—Total Cost of Light at different Prices of Current for various Makes of Lamps.

fracture again after welding. Perhaps this is partly due to the shortness of the loops and consequent greater mechanical strain on the joint, and partly to the fact that their temperature is considerably lower than that of tungsten filaments.

The broken-line curves on the various sheets give the relation between the cost of energy in pence per unit and the useful life. They are, of course, obtained from the total cost curves. In Fig. 10 are curves giving the relation between the least total cost of light (for

lamp and energy) and the voltage for four typical cases. These have been constructed by taking the minimum points of the total cost curves mentioned above. The broken lines on these sheets are drawn through the minimum points.

Consider the tantalum—*i.e.*, Set 1 first. All the candle-power curves show a distinct rising at first and then a gradual fall, the slope of which depends on and increases with the voltage at which the lamp is run. In nearly all cases the actual life curves are very wavy with alternate rising and falling of candle-power.

To illustrate this I have reproduced the actual curves obtained from this set, though the same peculiarity was to some extent met with in all. It seems to be due partly to a variation of the current, and therefore, since the voltage was constant, to an alteration of the resistance. It may possibly occur owing to changes in the surface of the filament. However, I am unable at present to explain it satisfactorily.

It is interesting to compare these curves with some obtained by O. Brant from Osram lamps,* which I have reproduced. They show the same general initial rise and gradual fall. Two of the lamps, namely, A 1 and 1 B, were still burning when these results were collected. The useful life of a lamp, and the drop in candle-power which it is advisable to allow for a given voltage, depend on the cost of current and the price of the lamp. The cheaper the current, of course, the longer the life, and the greater the admissible drop.

Taking current at 5d. per unit as an average price, and the lamp run at rated voltage, then it pays to throw the lamp away as soon as the candle-power has fallen to 3 per cent. below its original value. This result appears startling at first, considering the large initial cost of the lamp. However, by time this point is reached the lamp has been burning for 1,500 hours at the best possible efficiency for the given potential difference at its terminals, so that the cost of the lamp per candle-hour has become small. In most cases the "total cost" curves are very flat near their minimum value, so that the exact time to "scrap" the lamp is not very clearly marked. When the lamps are run at a low voltage the efficiency curve rises very slowly, and the smashing-point is not reached until the "lamp cost" curve has become fairly flat, which means a long economical life, for the candle-power is low but varies slowly. On the other hand, when run at a higher voltage the changes in the lamp take place more rapidly, the efficiency curve rises quicker, and consequently the economical life is shorter.

The curves in Fig. 11 bear out this conclusion.

From the curves in Fig. 10 it appears, as would be expected, that the dearer the current the higher the potential difference at lamp terminals, and therefore the efficiency at which it pays to burn it. The values from the curves are as shown on page 189.

The curves become more concave as the price of the current goes up owing to the greater effect of the efficiency on the total cost. It appears that it would be good practice to overrun the lamps from 2 to

* *Electrotechnische Zeitschrift*, vol. 29, p. 1263, 1908.

6 per cent., and for a life of 1,300 to 700 hours according to the price of current. With current at 4d. per unit the drop in candle-power

Price of Current.	Per Cent. Voltage.	Hours.
8d.	106·0	700
6d.	105·0	950
4d.	104·0	1,050
2d.	102·5	1,300

from the initial giving the most economical life appears to be about 5 per cent. This is very much less than that commonly allowed in the case of carbon lamps.

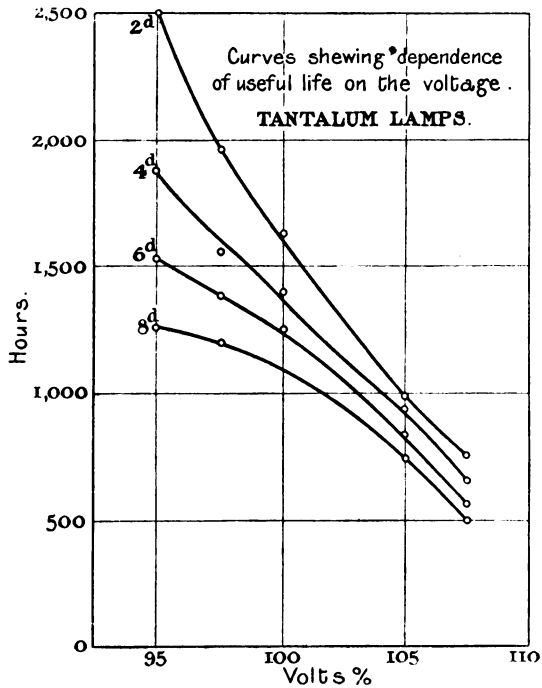


FIG. 11.

Tungsten Lamps.—These are included in Sets 2, 3, 4, 5, and 6. Many of the remarks made on tantalum lamps apply equally well to

these. The initial rise in candle-power mentioned in connection with tantalum lamps is in most cases not apparent. It occurs most markedly in Set 6. The candle-power curves, generally speaking, show a continual drop from the start. In many cases the drop is very rapid at first, and then becomes less and less so until they become almost horizontal. When this is so there is found to be very little blackening of the bulbs. The total cost-curves reproduced in Fig. 10 all show the same characteristics as those for tantalum lamps. These curves in the case of Set 3 show a continual drop without a minimum point. This is due to a very great improvement in the efficiency of the lamps at higher voltages without a corresponding shortness of absolute life or greater steepness of the life curves. The following lamps were still burning when these results were collected :—

Set 1.	Set 2.	Set 3.	Set 4.	Set 5.	Set 6.
A B	A B′ C D	A C E F	A B D	A B	A B C D E

Collecting these together we get :—

Voltage	95·0 A	97·5 B	100·0 C	102·5 D	105·0 E	107·5 F
Number of lamps still burning	6	5	3	3	2	1

From this it would seem that the increased potential difference has an effect on the absolute besides the useful life. The useful life of tungsten lamps is much longer than that of tantalums. If carelessly handled the absolute life would probably be shorter owing to the greater fragility of the filament. It may be noted that the area of bulb exposed to blackening is greater in the case of all the tungsten lamps tested than in the case of the tantalums. This would help to prolong the efficient life. Practically all the blackening takes place in a belt opposite the filament, the pip end keeping clear.

The allowable drop with tungsten lamps is on the average greater than with tantalum lamps. This is owing to the absence of an initial rise and the presence of an initial drop of candle-power as mentioned above. A factor which affects the mechanical life of a lamp is the method of anchoring the filament at the pip end. Some trouble was experienced with the lamps of Set 5. In their case the tops of the loops are fastened by a globule of glass to a short piece of wire which is cemented to the end of a small coiled spring, the object of which is to keep the filaments in tension. When such a lamp was burning a small jar was sufficient to detach the loop from the spring owing to the glass softening. When this happened great care had to be taken to avoid fracturing or short-circuiting the loop. In one or two cases when being photometered (with the pip end upwards) a loop leaned outwards until the glass globule stuck to the

PRELIMINARY MEASUREMENT OF LAMPS AT RATED VOLTAGE.

Volts, 100.				Amperes, $\frac{\text{Watts}}{100}$			
Lamp No.	Watts.	Candle-power.	Efficiency.	Lamp No.	Watts.	Candle-power.	Efficiency.
1 A	37·80	20·16	1·88	4 A	34·7	28·06	1·465
1 B	36·60	16·02	2·28	4 B	34·5	26·44	1·305
1 C	38·90	17·90	2·17	4 C	34·8	27·30	1·270
1 D	39·50	19·03	1·86	4 D	33·9	25·70	1·320
1 E	38·60	18·20	2·12	4 E	35·0	25·66	1·360
1 F	39·50	20·35	1·94	4 F	28·4	21·61	1·310
2 A	29·70	21·50	1·25	(4 F′)	34·5	25·40	1·360
2 B	28·20	19·86	1·42	(4 F″)	34·6	26·30	1·320
2 C	29·40	20·76	1·42	5 A	31·6	25·22	1·250
2 D	29·10	19·67	1·48	5 B	30·5	25·65	1·190
2 E	28·90	19·03	1·57	(5 B′)	31·8	25·56	1·240
(2 F)′	28·10	19·08	1·47	5 C	30·8	23·35	1·310
2 F	31·10	24·34	1·28	(5 C′)	30·4	21·60	1·410
3 A	33·75	24·30	1·39	5 D	30·9	24·22	1·280
3 B	32·70	23·80	1·37	5 E	30·5	23·75	1·280
3 C	32·80	23·14	1·42	(5 E′)	32·0	25·55	1·250
3 D	33·60	22·78	1·48	5 F	30·4	24·25	1·250
(3 D)′	32·90	22·62	1·45	6 A	27·8	24·18	1·150
3 E	34·90	24·34	1·43	6 B	28·3	26·10	1·080
3 F	33·30	22·20	1·50	6 C	27·8	22·80	1·220
—	—	—	—	6 D	28·1	23·32	1·210
—	—	—	—	6 E	28·0	23·45	1·200
—	—	—	—	6 F	27·6	23·95	1·150
—	—	—	—	6 G Sub-standard	27·6	23·68	1·160
—	—	—	—				

Calculations for Plotting Curves, etc.

Hours.	Candle-power.	Candle-power per Cent.	Candle-hours.	Watt-hours.	Watt-hours / Candle-hours	Pence per Candle-hour for Lamp = 30d. / Candle-hrs.
Lamp No 1 A. Cost of Lamp, 2s. 6d.						
0	14·00	100·0	0	0	2·480	—
250	15·00	107·1	3,660	8,680	2·370	0·008200
500	15·40	110·0	7,530	17,420	2·316	0·003980
600	15·45	110·3	9,060	20,950	2·310	0·003310
1,000	14·60	104·2	15,180	35,200	2·320	0·001980
1,500	14·00	100·0	22,300	53,000	2·376	0·001340
2,000	13·30	95·0	29,120	70,800	2·432	0·001030
2,250	12·90	92·0	32,405	79,750	2·463	0·000925
2,500	12·50	89·3	35,585	88,638	2·490	0·000843
2,750	12·00	85·6	38,647	97,526	2·520	0·000775
3,000	11·90	85·0	41,634	106,414	2·560	0·000720
Lamp No. 1 B. Cost of Lamp, 2s. 6d.						
0	13·70	100·0	0	0	2·53	—
175	15·50	113·1	2,550	6,160	2·42	0·011800
250	15·80	115·3	3,725	8,820	2·37	0·008050
500	16·65	121·6	7,697	17,720	2·31	0·003900
750	16·50	120·5	11,841	26,710	2·26	0·002540
1,000	15·75	115·0	15,879	35,760	2·25	0·001890
1,250	14·50	106·0	19,660	44,810	2·28	0·001530
1,500	13·80	100·8	23,200	53,830	2·32	0·001290
1,750	13·25	96·8	26,587	62,850	2·36	0·001130
2,000	12·60	92·0	29,812	71,850	2·41	0·001000
2,250	12·00	87·5	32,822	80,825	2·46	0·000915
2,500	11·75	85·6	35,790	89,787	2·51	0·000838
2,750	11·40	83·1	38,684	98,737	2·55	0·000775
3,000	11·20	81·6	41,509	107,674	2·59	0·000724
Lamp No. 1 C. Cost of Lamp, 2s. 6d.						
0	17·75	100·0	0	0	2·175	—
175	20·90	117·7	3,450	6,810	1·980	0·00870
250	20·00	113·0	4,930	9,740	1·980	0·00610
400	19·00	107·0	7,840	15,600	1·990	0·00383
750	18·60	104·7	14,470	29,590	2·060	0·00207
1,250	17·90	100·9	23,600	49,400	2·090	0·00126
1,750	17·00	95·8	32,180	69,400	2·150	0·00093
2,250	15·50	87·4	40,310	89,250	2·220	0·00075
2,500	14·80	83·5	44,097	99,187	2·250	0·00068
2,750	14·10	79·5	47,709	109,062	2·290	0·00063
3,000	13·30	75·0	50,134	118,902	2·370	0·00060

CALCULATIONS FOR PLOTTING CURVES, ETC. (*continued*).

Hours.	Candle-power.	Candle-power per Cent.	Candle-hours.	Watt-hours.	$\frac{\text{Watt-hours}}{\text{Candle-hours}}$	Pence per Candle-hour for Lamp $= \frac{\text{30d.}}{\text{Candle-hrs.}}$
Lamp No. 1 D. Cost of Lamp, 2s. 6d.						
0	21·60	100·0	0	0	1·875	—
250	23·00	106·5	5,550	10,000	1·800	0·005400
425	21·60	100·0	9,560	17,600	1·840	0·003140
1,175	19·45	90·0	24,950	48,600	1·950	0·001200
1,380	18·36	85·0	28,860	57,200	1·980	0·001040
1,510	17·30	80·0	31,190	62,700	2·010	0·000962
1,760	15·10	70·0	35,340	73,250	2·074	0·000849
1,875	14·00	64·8	36,650	77,900	2·121	0·000819
2,000	12·25	56·7	38,360	83,650	2·182	0·000783
Lamp No. 1 E. Cost of Lamp, 2s. 6d.						
0	21·40	100·0	0	0	1·940	—
160	26·00	121·5	3,762	6,650	1·768	0·007980
465	23·40	109·2	11,210	19,920	1·778	0·002680
775	21·25	99·3	18,220	33,140	1·818	0·001650
890	20·19	94·3	20,420	38,000	1·860	0·000147
1,000	19·20	89·6	22,800	43,100	1·890	0·000132
Lamp No. 1 F. Cost of Lamp, 2s. 6d.						
0	26·50	100·0	0	0	1·685	—
100	27·50	103·8	2,705	4,455	1·650	0·01110
200	25·80	97·4	5,385	8,900	1·650	0·00556
250	25·05	94·5	6,656	11,122	1·670	0·00450
400	23·50	88·6	10,301	17,752	1·720	0·00291
500	21·95	82·8	12,576	22,157	1·760	0·00238
625	19·70	74·4	15,132	27,651	1·830	0·00198
750	16·80	63·4	17,413	33,113	1·900	0·00172

bulb. No harm was caused by this unless it became unstuck again. In some cases the lamps burnt for some hundreds of hours with the loop stuck as above.

As far as tightness of filament is concerned the best lamps were Set 3, in which the loops were simply threaded through a loop at the end of a piece of nickel wire, the other end of which was stuck into the top of the glass pillar. There was not the slightest sagging with any of these lamps.

The following table gives a comparison of the different makes. Below it are given for comparison some figures for carbon lamps taken from Mr. Hirst's paper, read before this Institution. The cost of energy

has been taken at 4d. per unit. The figures are reduced to English candle-power and 9d. per lamp.

Lamp.	Initial Candle-power.	Volts per Cent.	Useful Life.	Mean Efficiency.	Candle-hours.	Cost per 1,000 Hours.		
						Renewals.	Current.	Total.
			Hours.			d.	d.	d.
Set 1 ...	21·50	105·0	970	1·87	22,200	1·350	7·50	8·850
2 ...	24·20	105·0	1,500	1·45	32,400	1·300	5·80	7·100
3 ...	30·00	107·5	2,300	1·29	67,464	0·640	5·16	5·800
4 ...	28·50	102·5	2,000	1·32	53,138	0·790	5·28	6·070
5 ...	31·20	107·5	1,900	1·34	47,500	0·880	5·36	6·240
6 ...	26·50	105·0	2,350	1·22	55,770	0·750	4·88	5·630
No. 1.........	15·10 (E.C.)	100·0	1,000	4·94	14,560	0·619	19·75	20·369
2.........	14·95 (E.C.)	100·0	1,000	4·06	14,400	0·628	16·25	16·878

No. 1, 100-volt, and No. 2, 200-volt carbon lamp.

The figures giving the life in hours are somewhat approximate, because the curves were very flat, and their minimum point indistinct. The duration of life is that giving the best economy. The actual life in some cases was much longer. The life curves show that many lamps were burning well at 3,000 hours. Unfortunately, I was not able to continue the tests further, or an even greater duration of life would probably have been obtained. The voltage is that which, according to the curve, gives the best economy. The actual potential difference at the lamp terminals is slightly less than this, owing to the drop in leads and surface contact. The efficiencies throughout have been calculated on this lower potential difference.

From these tests it appears that the cost of lighting with tungsten lamps amounts to about 6·2d. per 1,000 candle-hours. If tantalum lamps are used the cost is about 8·8d., or 42 per cent. more. When carbon lamps are used the cost is still greater. According to the figures above quoted the cost is about three times as much as for tungsten. In the case of metallic filament lamps 85 per cent. of the cost is paid for the energy consumed, and 15 per cent. for the lamp itself, while with carbon lamps this latter item only amounts to 5 per cent. of the whole.

The tantalum lamps are much tougher than the tungsten ones, which is a great advantage when they are to be subjected to rough usage. They are sometimes preferred on account of the agreeable colour of their light, which is not so white as that of the tungsten lamps. This difference in colour was very noticeable in photometering the lamps.

A drawback to most electric incandescent lamps having a glowing filament is the bright star-shaped figure they cast immediately below them when supported vertically. This is more marked with the kinds having few loops, as, for example, the Osrams, and is least noticeable in the case of the tantalums owing to the arrangement of the

filament. It could be prevented by frosting the pip end of the bulb. The efficiency of the lamp would be lowered very little, since the perpendicular candle-power is very much less than the horizontal.

In shop-window lighting, etc., the lamps are often placed in close

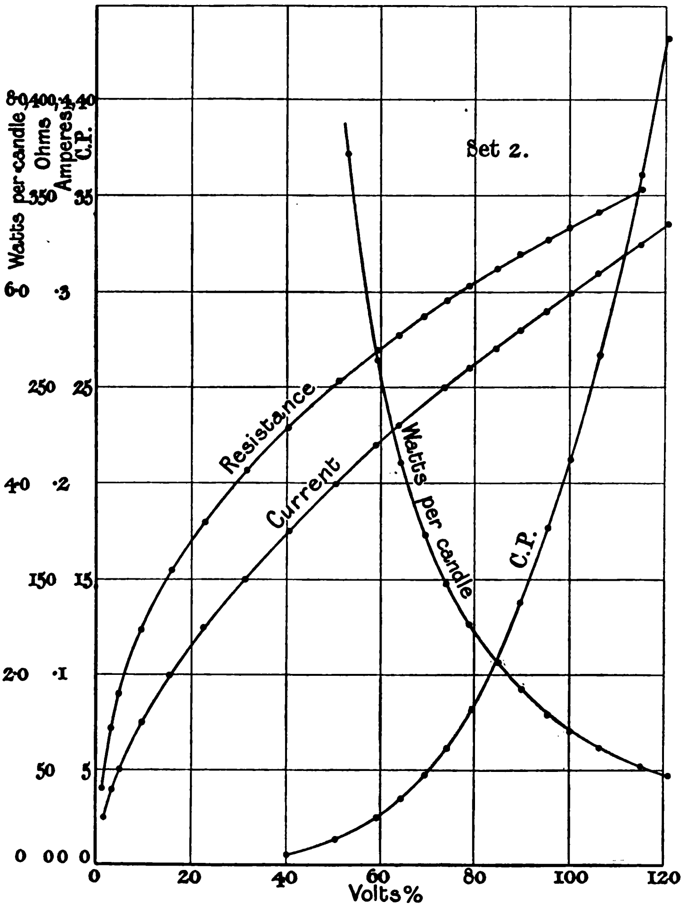


FIG. 12.

proximity to perishable goods. The outside temperature of the bulbs was therefore measured. It was done by fastening a copper-eureka thermo-couple to the bulb at the level of the centre of the filament. The lamps were run separately and at their normal voltage.

The results given on page 196 are the average obtained.

The lamps absorbing the most power have naturally the highest

temperature. The temperature of the bulbs apparently increases with the life. This may be due to the presence of the black deposit on the bulbs, which absorbs some of the rays and consequently

Lamp.	New.		After 1,400 Hours.	
	Amperes.	Temperature.	Amperes.	Temperature.
Tantalum	0·390	68° C.	0·400	95° C.
Tungsten	0·302	46° C.	0·311	61° C.

Room temperature, 15° C.

becomes heated. The end of the bulbs keeps comparatively cool because the radiation is much less in that direction. The lamps were

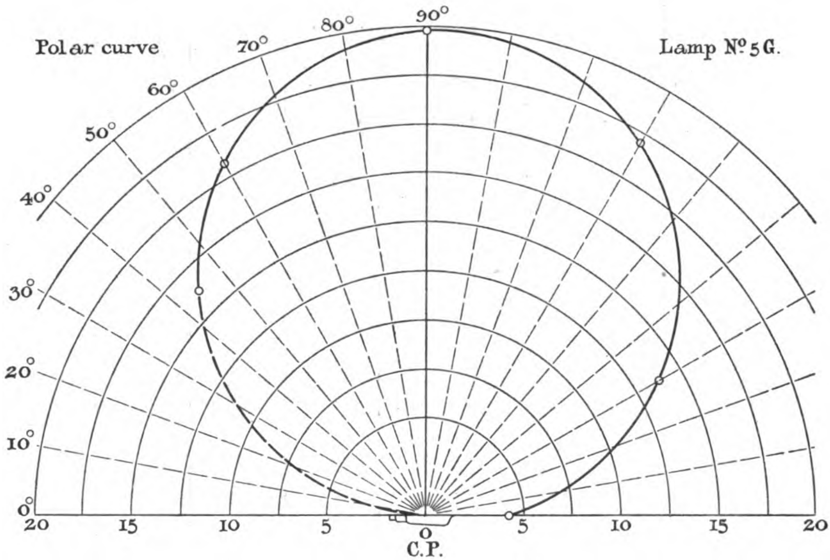


FIG. 13.

found to flicker more than carbon lamps when placed on an unsteady circuit. This is owing to the lower thermal capacity of the filaments. For this reason they are not suitable for circuits with alternating currents of low frequency. Methods have been tried to overcome this difficulty—for example, putting three lamps in series under one globe.

For slow changes in potential difference about the normal, however,

the alteration in candle-power is not so great as is the case with carbon lamps. Some tests were made in order to determine the dependence of the candle-power and efficiency on the voltage. A typical set of curves is given in Fig. 12.

The figures for the different makes of lamps for a 3 per cent. variation of volts above and below the normal are as follows :—

	Set 1.	2.	3.	4.	5.	6.	Carbon.
Variation in candle-power per cent....	22·6	21·8	20·9	22·4	21·5	23·4	34

The average for metallic filament lamps works out at 22 per cent., so that the variation with carbon lamps is 50 per cent. greater.

Some tests were also carried out in order to obtain the mean spherical candle-power. The lamps were run at rated voltage. When being photometered they were fixed in a stand which enabled them to be turned through a complete circle in planes perpendicular to and parallel with the filament.

The following table gives the average figures obtained :—

A. Mean Spherical Candle-power.	B. Mean Hemispherical Candle-power.	C. Mean Horizontal Candle-power.	D. Perpendicular Candle-power.	$\frac{A}{C}$	$\frac{D}{C}$
17·6	18·6	22·7	4·0	0·78	0·18

The mean spherical candle-power is thus about 22 per cent. less than the mean horizontal candle-power, and the vertical candle-power is only 18 per cent. of the horizontal.

I have reproduced a representative polar curve in Fig. 13.

In conclusion, I desire to express my thanks to Dr. Kapp for much valuable help and encouragement during the course of this research, also to the engineering staff of the University of Birmingham for the loan of apparatus and facilities afforded for carrying out the tests.

Discussion.

Dr. W. E. Sumpner: Having at various times made a number of tests on lamps, I should like to point out the large amount of skill and trouble needed to carry out such tests as those described in Mr. Lavender's paper. The author gives a mass of experimental data in the form of tables or diagrams. They will all of them repay study, and some of them need study before their full meaning can become clear. The paper deals with the best working voltage and with the best working life of certain lamps. But although it may be interesting to know the exact voltage at which a particular lamp works best, what Dr. Sumpner.

Dr. Sumpner. we wish to know is the proportionate loss of efficiency or life when the best voltage and the working voltage differ by a given percentage, and this point is not clearly brought out. The important thing to know about any maximum is not the exact point at which it occurs, but whether it seriously matters if we are near the maximum or not. Is the maximum like some spot on the Sahara, from which you may wander miles and miles without being appreciably lower; or is it like the top of the Matterhorn, where, if you step a little to one side, you may go on falling for the rest of your life? Many have written about the "smashing-point" of lamps, but I do not know that any one has pointed out that with carbon lamps under ordinary conditions the total cost per candle-hour does not sensibly alter after about 300 hours' use, whether the life is determined at 300 hours or at any later time up to about 1,000 hours. There is, no doubt, a moment at which it is theoretically best to smash the lamp, but in practice no one knows this moment. The important fact to know about carbon lamps is that it is quite economical to remove them after about 300 hours' use, and certainly as soon as they become appreciably dull. What we want to know about a lamp is not its life for minimum cost per candle-hour, but the two limits between which its cost differs less than, say, 5 per cent. from this minimum. With carbon lamps the first limit is reached after about 300 hours, and owing to the falling off of its efficiency the second limit is reached at, say, 1,000 hours, and in most cases before the lamp gives way. But with the new and more costly wire lamps the first limit is not reached till about 500 hours, and the second limit does not seem to be reached at all in practice. The efficiency falls off very little. This makes the second limit occur long after the lamp gives way, in spite of the fact that the life of the wire lamp much exceeds that of the carbon lamp. The moral is, remove a carbon lamp directly it is dull, but use a wire lamp until it gives way.

In connection with the plotting of efficiency results I have found a diagram due to Dr. D. K. Morris and Mr. Hulse very useful.* In this diagram the light in candle-hours is plotted vertically and the cost of current horizontally to the right (this cost is essentially proportional to the number of hours burning). From the origin is set off horizontally to the left the cost of the lamp. From the point so determined lines can be drawn to the candle-hour curve, and the slope of any of these lines represents the number of candle-hours obtained per unit of cost for the corresponding time of use. After the first few hours' burning it will be found that the slope of all these lines is sensibly the same. Unless the efficiency of the lamp falls off rapidly, the curve bends very little, and it becomes difficult to determine the point of maximum efficiency represented by the tangent to the curve.

Mr. Solomon. Mr. MAURICE SOLOMON: I agree with Dr. Sumpner that these curves showing the economical life do not give much valuable information, because they do not bring out clearly the difference it makes if the economical life is exceeded. I think they have another disadvan-

* *Journal of the Institution of Electrical Engineers*, vol. 31, p. 1185 (1902).

Mr. Solomon.

tage, namely, that they lead to a conclusion which it is absolutely impossible to carry into practice. As Dr. Sumpner has pointed out, it is ridiculous to tell anybody that their lamps should be thrown away when their light has fallen 3 per cent. from its original value. Nobody could possibly tell when that point is reached without sending the lamps to be tested, and this would certainly not be an economical thing to do. There are two natural limits which determine the life in practice; one of these is the breaking of the lamp, and the other is that the candle-power falls until it is no longer sufficient for the purpose for which it is required. What is generally known as the useful life of the carbon filament lamp is, no doubt, founded upon the assumption that when we want 100 candles we shall not be satisfied with less than 80, although we should be satisfied with 97; and it should be noted that if the useful life of the carbon filament lamp is worked out on this basis it will generally be found to be double the economical life as calculated by means of curves such as Mr. Lavender's. The paper shows a great many very valuable curves, but they are, as the author tells us, only samples of a larger number which he has taken. There is one point, however, which I do not think is emphasised sufficiently. All the curves in this paper are deduced from the results obtained by the test of a single lamp. A reference to the curves in Fig. 2 will show the actual results obtained in practice. The curves in this figure are very irregular, and in order to deduce further results from them the curves have to be smoothed out as shown in Fig. 3. This smoothing-out process, then, has been applied to all the actual test results obtained, and it is from the smoothed-out curves that he obtains the further curves in Figs. 9 and 10, from which he draws his conclusions as to the most economical life. Now on further reference to a curve such as curve C in Fig. 9, which I only pick as an example, recollecting that the author's conclusions depend on determining the minimum point of this curve, which for a great part of its length is practically horizontal, every one will agree, I think, that these conclusions must be received with great caution. What is actually done, therefore, is that a life test is made on a *single* lamp, the variations in the results obtained in this test are smoothed out, secondary curves are deduced from the smoothed-out life test curve, and a very undefined minimum point is picked out from these secondary curves; the least that can be said under these circumstances is that the conclusion that the candle-power should not fall more than 3 per cent. rests on a very unsound basis.

I had occasion myself a short time ago to work out a large number of these curves, and I came to the conclusion that unless one were extraordinarily honest one could bring the minimum point of curves such as curve C to any desired point. I do not mean to suggest that this is done wilfully, but I think that it is done subconsciously; and if this were not the case I do not believe one could get such remarkable consistency as is shown by the curves in Fig. 10 when these curves are deduced from tests on a single lamp. It may be remarked, however,

Mr. Solomon.

that the curves in Fig. 10 show that the makers for the most part rate their lamps very close to the best rating. Take, for example, set No. 4, where the actual minimum of these curves occurs at 102 volts, whilst the lamps are rated by the makers at 100 volts. This shows, I think, that the makers know what they are supplying and know the characteristics of their lamps, and have succeeded in getting remarkably near to what may be expected to give the best results in practice. I hold very strongly the opinion that papers of this sort should be based on average results from a large number of lamps if the conclusions that are drawn from them are to be of any real practical value to those engaged in the industry.

Mr. Forster.

Mr. A. LINDSAY FORSTER: Whereas until recently people have been concerned mainly with comparing carbon and metallic lamps, we are now comparing metallic filament lamps one with another. It is very noticeable that a large amount of space is devoted by Mr. Lavender to the tantalum lamps, whereas very little relatively is devoted to comparing the tungsten lamps one with another. It would appear that the differences amongst these are sufficient to make it worth while to bring them out. A case in point is the small variation in cost per candle-hour with variation of volts for set 6. Then we find on page 190 that five out of six lamps of the same set were still running at the time the paper was written. Further, the same set consumes on an average (page 191) 1·17 watts per candle-power, while set 3, which has apparently the highest consumption of the tungsten lamps, requires 1·43 watts per candle. Also on page 192 one will find a lower cost per 1,000 candle-hours for set 6 than for any other set. Taken together, these all show that No. 6 make is much the best of the tungsten lamps. I am surprised that so much space has been devoted to curves of the tantalum lamp performances, which are not typical of any of the other makes. I feel myself that it would be worth while to have the principal results re-arranged. The paper contains much useful information which is not brought out, and a carefully written *résumé* of it would bring out some relatively important points.

Mr. Needham.

Mr. H. H. NEEDHAM: As may be seen in Fig. 2, the candle-power first rises and then slowly drops off. Most makers aim to get near this maximum point before the lamps are sent out, for unless this is done the final candle-power of the lamp is very uncertain. It is therefore usual to age or burn all the lamps before they are delivered to the customer. The paper suggests that the irregularities in the curves are due to actual changes in candle-power. It seems much more probable that they are due to the method of measurement, as the readings were taken at constant current, and a small variation of current causes a large variation in candle-power. A point of some interest is the manufacturer's rating. His first aim is to get a lamp of long life, as the customer appreciates this more than he does the point of most economic life. In addition, the manufacturer desires a lamp of a little higher efficiency than his competitors. A point well shown by the paper with regard to tungsten lamps is that they may be burned as

long as they hold together, because the percentage drop in candle-power is small enough to be negligible. Their useful life is sometimes ended by the discoloration of the bulb, but more often by the actual breaking of one of the filaments. Mr. Needham.

Mr. W. E. MILNES: I do not know that this paper helps the consumer much. I should not like to visit some of our consumers and tell them they must scrap the metallic lamp after 1,500 hours' burning. A great many of them would be content if they got lamps which would burn 1,500 hours. As regards the question of voltage, some of the voltages are worked out on the tables to three places of decimals. I think some allowance should be made for the variation one is bound to have on town mains. We find that here in the centre of the town it is possible to put in 240- or 235-volt lamps, while on the outskirts we must put in 230-volt lamps. It is always advisable to use a higher voltage lamp near the centre of supply, and the lamp has a longer life. I do not suggest that our voltage is erratic, but rather that these new lamps are wrongly marked by the makers. In fact, one maker is a great sinner in this respect. A consumer recently complained of the premature failure of his lamp, and we got a dozen he had just purchased from this maker and tested them. They were all marked 110 volts, and we found that if they had been correctly marked the voltage would range from 87 to 114, while each was guaranteed as suitable for series-burning on a 220-volt circuit. We were told our pressure was not suitable for metallic filament lamps, and the customer was by no means satisfied with our explanation. Mr. Milnes.

Mr. LAVENDER (*in reply*): With regard to Dr. Sumpner's remarks as to the effect on the efficiency of a difference between the working voltage and that best suited to the lamps, I think the required information is given graphically by the curves in Fig. 10 which show the effect produced on the total cost. This is, after all, the real issue. The effect depends on the price of energy, and also on whether the lamps are over or under run. Taking current at 4d. per unit and a 2½ per cent. difference in voltage, either up or down, the resulting increase in the total cost will not be more than 5 per cent., and 10 per cent. in the case of "Tantalum" and "Tungsten" lamps respectively. This shows that the question of the voltage has an important bearing on the economic running of the lamps. Mr. Lavender.

Several gentlemen have suggested that I have been too conservative in estimating the useful life of the lamps. In order to compare the cost of lighting with different makes of lamps, it was necessary to place them all on a common basis. Hence the calculation of the theoretical "smashing-point" and the determination of the best possible output from the lamps. Once the minimum-point has been reached the curves connecting the total cost with the life remain very flat; more so in the case of tungsten than with tantalum lamps. Consequently the increase of cost involved in running beyond the economical life, and even to breaking-point, is quite negligible. In practice it will be found best to burn the lamps on a voltage a little above the

Mr. Lavender.

rated, say 3 per cent., and until they break. With ordinary care there should be no trouble in obtaining an average life of 2,500 hours with metallic filament lamps. I should like to point out, in reference to Mr. Needham's remarks, that all the measurements were taken to three places of decimals, and repeated three times to ensure accuracy.

ORIGINAL COMMUNICATION.

THE RELATION BETWEEN THE STATOR AND ROTOR CIRCUITS OF THE SINGLE-PHASE INDUCTION MOTOR.

By CHARLES F. SMITH, Member.

(*Received July* 26, 1909.)

CONTENTS.

INTRODUCTORY.

The following paper is an attempt to make clear the connection between the current and voltage in the stator of a single-phase induction motor and the current and voltage in the rotor. The author has failed to find a satisfactory statement of these relations in a form suitable for use in practical calculations, and has been led to make the simple measurements and deductions which follow in order to supply this omission from the literature of the subject.

The experiments confirming the theoretically deduced relations were made on several 3-phase inducton motors. The figures given in the present paper all apply to one motor, although similar measurements were made on other machines for the sake of further confirmation. As representing cases likely to arise in practice, the stator of the motor was sometimes supplied with two of its three phase-windings in series, while sometimes only a single phase-winding was supplied.

The motor was a standard 5-H.P. 220-volt 50-cycle 4-pole machine, made by the Allgemeine Elektricitäts Gesellschaft, of Berlin. The stator had 48 slots, with star-connected winding in 3 slots; the rotor had 60 slots and a star-connected winding in 5 slots. The stator resistance was 0·25 ohm per phase and the rotor resistance about 0·11 ohm per phase, the latter varying somewhat with the current on account of brush contact resistance.

Voltage of Rotor on Open Circuit.

Assuming the rotor to be revolving in a sinusoidal field produced by a single-phase current in the stator winding, we may calculate the theoretical value of the voltage induced in a coil of the rotor as follows:—

Let $\phi = \Phi \sin\theta$ be the value of the stator flux and a the angle between the plane of the rotor coil and the axis of the stator flux. Then $\phi \sin a$ may represent the flux entering the rotor coil.

Let n = frequency of rotation = revs. per second of rotor × number of pairs of stator poles; also—

f = frequency of stator supply in cycles per second.

We may write a in the form—

$$a = \frac{n}{f}\,\theta + \beta,$$

where β is a constant for any particular coil, and indicates the angular displacement of the coil from the axis of the flux at the moment when $\phi = 0$.

Then—

$$\text{Flux entering coil} = \phi \sin a = \Phi \sin\theta \sin\left(\frac{n}{f}\,\theta + \beta\right).$$

Voltage induced in coil

$$= t_2 \frac{d}{dt}(\phi \sin a)\, 10^{-8} = \frac{t_2}{2\pi f\, 10^8}\,\frac{d}{d\theta}\left[\Phi \sin\theta \sin\left(\frac{n}{f}\,\theta + \beta\right)\right],$$

t_2 being the number of turns of the coil.

On making the substitution $\theta = 2\pi f t$ and writing for briefness the letter E_2 in place of $\dfrac{t_2}{4\pi f\, 10^8}\,\Phi$, we have the voltage induced in the coil at any instant—

$$v = 2 E_2 \frac{d}{d\theta}\left[\sin\theta \sin\left(\frac{n}{f}\,\theta + \beta\right)\right]$$

$$= 2 E_2 \left[\frac{n}{f}\sin\theta \cos\left(\frac{n}{f}\,\theta + \beta\right) + \sin\left(\frac{n}{f}\,\theta + \beta\right)\cos\theta\right] \quad . \quad . \quad (1)$$

This may be expanded into—

$$v = 2 E_2 \left[\frac{n}{f}\sin\theta\left(\cos\frac{n}{f}\,\theta \cos\beta - \sin\frac{n}{f}\,\theta \sin\beta\right)\right.$$

$$\left. + \cos\theta\left(\sin\frac{n}{f}\,\theta \cos\beta + \sin\beta \cos\frac{n}{f}\,\theta\right)\right] . \quad . \quad . \quad . \quad . \quad (2)$$

When the rotor coil is stationary we shall obtain the induced phase volts by writing $n = 0$, so that—

$$v = 2\,E_2 \cos\theta \sin\beta.$$

This may have any virtual value between zero and $\sqrt{2}\,E_2$ according to the position of the rotor, *i.e.*, according to the value given to β.

At a low speed the voltage will assume a virtual value practically equal to $\frac{1}{\sqrt{2}}$ of its maximum value, so that it may be written—

$$v_{\text{virt.}} = \frac{1}{\sqrt{2}} \cdot \sqrt{2}\,E_2 = E_2 \text{ virtual volts.}$$

This voltage we shall subsequently refer to as the "virtual stationary" rotor voltage.

In order to obtain the voltage per phase for the revolving rotor in its simplest form, we may put $\beta = 0$ and write equation (1) as follows:—

$$v = E_2\left[\frac{n}{f}\left(\sin\frac{f+n}{f}\theta + \sin\frac{f-n}{f}\theta\right) + \sin\frac{f+n}{f}\theta - \sin\frac{f-n}{f}\theta\right]$$

$$= E_2\left[\left(1+\frac{n}{f}\right)\left(\sin\frac{f+n}{f}\theta - \left(1-\frac{n}{f}\right)\sin\frac{f-n}{f}\theta\right]\right. \quad . \quad . \quad (3)$$

This expression denotes two voltages of differing frequencies, one having a crest value $\left(1+\frac{n}{f}\right)E_2$, and the other with a crest value of $\left(1-\frac{n}{f}\right)E_2$.

The resultant voltage will have a virtual value—

$$v_{\text{virt.}} = \frac{E_2}{\sqrt{2}}\sqrt{\left(1+\frac{n}{f}\right)^2 + \left(1-\frac{n}{f}\right)^2} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

so long as n is not zero, *i.e.*, so long as the two component waves have unequal frequencies.

If we now imagine the rotor speed to be gradually reduced to a very low value, the voltage given by equation (4) will fall until it approximates to the value obtained by putting $n = 0$ in the expression for the virtual voltage. Thus for very slow rotation the rotor voltage approximates to—

$$v_{\text{virt.}} = \frac{E_2}{\sqrt{2}} \cdot \sqrt{2} = E_2,$$

which is the "virtual stationary" value already mentioned.

When n becomes actually equal to zero, the voltage given in equation (3) consists of 2 waves of *equal* frequency and identical in phase. The crest value of this voltage is $2\,E_2$, and its virtual value—

$$v_{\text{virt.}} = \sqrt{2}\,E_2.$$

This is the "maximum stationary" rotor voltage. When $n=f$ we again find by substitution in (4) that—

$$v_{\text{virt.}} = \sqrt{2}\,E_2.$$

Equation (3) forms the basis for the treatment of the single-phase induction motor as equivalent to two polyphase motors having opposite directions of rotation.

The curves in Fig. 1 show the experimental values of the rotor voltage on open circuit, corresponding to equation (4). The curves

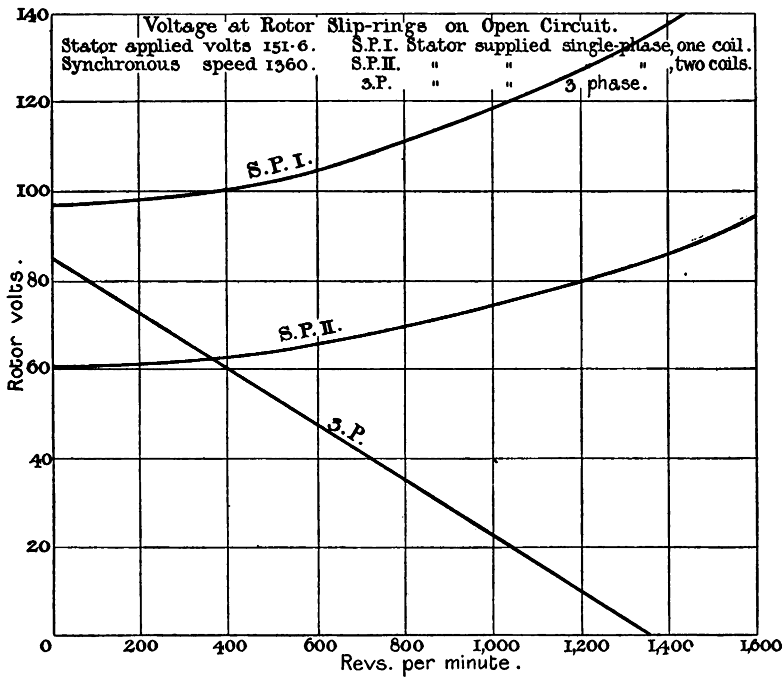


FIG. 1.

indicate the slip-ring voltage of a 3-phase motor with the stator supplied under the following conditions and the open-circuited rotor driven by a separate motor at various speeds. They coincide with the theoretical values represented by equation (4).

Curve (3 P.). 3-phase supply at 151·6 volts to the star-connected stator.

Curve (S.P.) II. As above, but with one supply wire interrupted, giving a single-phase supply to two stator coils in series.

Curve (S.P.) I. A voltage of 151·6 supplied to a single coil of the stator (from the star-point to one terminal).

The following table gives the principal results shown by the curves :—

Nature of Supply.	Stator Voltage.	Rotor Voltage at Slip-rings.		
		Maximum Stationary.	Virtual Stationary.	Synchronous.
Three - phase, star-connected ...	151·6	85·3	—	—
Single-phase, 2 coils in series	151·6	85·3	60·3	85·3
Single-phase, 1 coil ...	151·6	137·5	97·2	137·5

The voltage of the single-phase motor given above as "maximum stationary" indicates the voltage with the rotor fixed in the position for maximum mutual induction between stator and rotor windings. The "virtual stationary" voltage is the value to which the voltage of the rotor approximates as its speed falls to zero. When the rotor rotates very slowly, its voltage fluctuates violently between zero and the maximum value given in the third column. At a speed just sufficient to give a steady deflection on a dead-beat voltmeter, the voltmeter indicates approximately the virtual value of a voltage whose maximum is the "maximum stationary" voltage given in the table. The voltages for the single-phase motor given in column four are accordingly seen to be practically $\frac{1}{\sqrt{2}}$ of the values in column three.

At synchronous speed the voltage becomes $\sqrt{2}$ times its virtual stationary value—*i.e.*, it is then equal to the "maximum stationary" value of column three. This condition evidently agrees with the theoretical value given by equation (4).

Ratio of Stator to Rotor Voltage on Open Circuit.

The ratio of stator voltage to the "virtual stationary" rotor voltage may conveniently be regarded as the ratio of voltage transformation for the motor. Its value for the particular motor under consideration may be obtained from the curves in Fig. 1.

In the case of a 3-phase motor, the ratio of voltage transformation with stationary rotor is given by—

$$k_3 = \frac{\text{stator volts per phase}}{\text{rotor volts per phase}} = \frac{t_1}{t_2} \text{ (approximately),}$$

where t_1 and t_2 are the number of stator and rotor turns per phase. With star-connected stator and rotor this ratio will be the same as that of stator terminal voltage to slip-ring voltage. In Fig. 1 this ratio is—

$$k_3 = \frac{151 \cdot 6}{85 \cdot 3} = 1 \cdot 78.$$

Suppose that, without any other change, one of the supply conductors is now disconnected. The stator will then be supplied single-phase, two phase-windings in series. The voltages between the three slip-rings of the stationary rotor will no longer be equal. The maximum voltage will be produced when two rotor phase-windings are in the position of maximum mutual induction with regard to the two active stator windings. The ratio of stator to rotor voltage will then be the same as when the stator was supplied 3-phase. In this case we shall have—

$$\frac{\text{stator volts}}{\text{maximum stationary slip-ring volts}} = \frac{t_1}{t_2} = k_3.$$

From Fig. 1 this ratio is $\frac{151 \cdot 6}{85 \cdot 3} = 1 \cdot 78$ as before. The rotor voltage per phase under these conditions is half the slip-ring voltage. With the rotor in slow rotation the voltages between all the slip-rings become equal and have a "virtual stationary" value $\frac{1}{\sqrt{2}}$ of the maximum value given above.

The rotor phase voltage is now $\frac{1}{\sqrt{3}}$ of the slip-ring voltage for a star-connected rotor. Thus if E_1 = applied stator voltage—

$$\text{Rotor slip-ring voltage} = \frac{1}{\sqrt{2}} \frac{E_1}{k_3} \text{ (= 60·3 volts in Fig. 1)}.$$

Consequently—

$$\text{Rotor phase voltage} = \frac{1}{\sqrt{2}\sqrt{3}} \frac{E_1}{k_3}.$$

When the same voltage is applied to a single phase of the 3-phase stator, we should find the same ratio of transformation if the flux formed in the single phase-winding of the stator affected only the winding of one phase of the rotor. When the rotor is stationary, but rotated into the position of maximum mutual induction, we shall, however, have the stator flux inducing voltage in two phases of the rotor. The ratio between stator volts and volts between the slip-rings connected to the two active rotor phases will consequently have a value—

$$\frac{\text{stator volts}}{\text{maximum stationary slip-ring voltage}} = \frac{t_1}{t_2 \times m} = \frac{k_3}{m}$$

where m is a constant greater than unity, but less than 2. In the present case the value of $\frac{k_3}{m}$ is seen to be (see table on page 207)—

$$\frac{151 \cdot 6}{137 \cdot 5} \quad \text{and} \quad m = \frac{137 \cdot 5}{85 \cdot 3} = 1 \cdot 61.$$

With the rotor in slow rotation, the voltages between the rings again become equal and of a value $\frac{1}{\sqrt{2}}$ of the stationary maximum value. The voltage per phase is $\frac{1}{\sqrt{3}}$ of the slip-ring voltage.

We have consequently the values—

$$\text{Rotor slip-ring voltage} = \frac{m}{\sqrt{2}} \; \frac{E_1}{k_3},$$

$$\text{Rotor phase voltage} = \frac{m}{\sqrt{2}\sqrt{3}} \; \frac{E_1}{k_3}.$$

At synchronous speed the rotor voltage (virtual value) is in each case $\sqrt{2}$ times its "virtual stationary" value as obtained with slow rotation.

Change in the Rotor Voltage as Rotation Begins.

The voltages in all the coils of the rotor will evidently have the same frequency and phase so long as the rotor is stationary, no matter what the position of the rotor may be.

Immediately the rotor is made to revolve, although the voltage per phase is still given by equation (4), the voltages in the various phases will reach their maximum values successively and not simultaneously. We shall, in fact, obtain a 3-phase voltage at the slip-rings, of a character such that the *virtual* values of the phase voltages will reach their maximum values successively. The voltage in any individual phase winding will be an alternating one, having at slow speeds approximately the frequency of the supply. As the rotor revolves, the amplitude of this voltage will vary, passing through a succession of virtual values with the frequency of rotation of the rotor. The virtual voltage values measured at the slip-rings will thus fulfil the relations of a 3-phase circuit having a frequency equal to the frequency of revolution.

In the case illustrated by Fig. 1, Curve S.P. II., the virtual stationary rotor voltage *per phase* will be approximately $\frac{1}{\sqrt{3}}$ of the value of 60·3 volts shown on the curve. The virtual voltage per phase with the rotor rotating slowly will consequently be $\frac{1}{\sqrt{3}}$ of 60·3 volts $= 34 \cdot 8$ volts approximately.

The following experiment shows that the slip-ring voltage may be regarded as a 3-phase voltage (so far as virtual values are concerned) practically as soon as rotation begins.

Three similar voltmeters were connected together in star and to the slip-rings of the single-phase motor. A fourth voltmeter was connected directly from ring to ring. With the rotor stationary, but rotated successively into different positions, the three voltmeters read unequally. The fourth voltmeter always indicated the arithmetic sum of the readings of the two voltmeters connected to the same rings. On rotating the rotor slowly all the voltmeter readings fluctuated violently; with a slightly higher speed (say 80 revs. per minute) they became steady and the three star-connected voltmeters read equally. The fourth voltmeter now read $\sqrt{3}$ times the voltage indicated by any of the others.

The steady readings of the three similarly connected voltmeters were $\frac{1}{\sqrt{2}}$ of the maximum reading indicated with the rotor stationary. The same point may be illustrated by another experiment. Connect the slip-rings of a single-phase motor to a star-connected starting resistance, connecting an ammeter in one phase and a voltmeter across one pair of rings. With stationary rotor, the quotient of the voltmeter reading divided by the ammeter reading will be the resistance of two legs of the starting resistance. If the rotor is now set in rotation the instruments will at first fluctuate violently, but at a fairly low speed will become steady enough to read. It is then found that the quotient $\frac{\text{voltmeter reading}}{\text{ammeter reading}}$ is lower than before in the ratio $\frac{\sqrt{3}}{2}$ and remains constant independently of the rotor speed. This shows that the virtual values of the currents in the limbs of the starting resistance change at a comparatively low speed from coincidence of phase to a relation producing the same virtual effect as that of a true 3-phase supply.

The conclusion to be drawn is that the ratios of voltage and current transformation in a single-phase induction motor must be considered to have each two definite values—one value with the rotor stationary and in the position for maximum mutual induction, and one value when the rotor is in rotation. There is no gradual change from one ratio to the other.

Writing k_3 for the ratio of transformation of the motor as a 3-phase machine and k_e for the ratio of stator volts to rotor phase volts when operating as a single-phase motor, we have, as already shown—

$$k_e = \frac{\sqrt{2}\,\sqrt{3}}{m} k_3,$$

where m is unity for a stator wound $\frac{2}{3}$ of its circumference, and about 1·6 when wound $\frac{1}{3}$ of its circumference.

ROTOR CIRCUIT CLOSED. ROTOR VOLTAGE.

When the rotor circuit is closed, rotation of the rotor in the stator flux produces an E.M.F. along an axis of the rotor perpendicular to that of the main flux. A magnetising current is thus produced in the rotor giving rise to an additional flux, which also induces an E.M.F. on the rotor coils.

On the assumption of zero rotor resistance and zero rotor leakage reactance, we may regard the rotor conductors as moving in two magnetic fields which are perpendicular to one another in both time and space, and which have instantaneous values represented by—

$$\text{Main flux} = \phi = \Phi \sin \theta\,;$$

$$\text{Perpendicular flux} = \phi_1 = \frac{n}{f} \Phi \cos \theta\,;$$

$$\text{Flux entering coil due to } \phi_1 = \phi_1 \cos \left(\frac{n}{f}\theta + \beta\right);$$

$$\text{Voltage due to this} = \frac{d}{d\,t}\left[\frac{n}{f}\Phi \cos \theta \cos \left(\frac{n}{f}\theta + \beta\right)\right]$$

$$= -2\,E_2\left[\frac{n}{f}\cos\left(\frac{n}{f}\theta + \beta\right)\sin\theta + \frac{n^2}{f^2}\cos\theta\sin\left(\frac{n}{f}\theta + \beta\right)\right] \quad . \quad (5)$$

The voltage due to flux ϕ has already shown to be (see equation (1))—

$$2\,E_2\left[\frac{n}{f}\sin\theta\cos\left(\frac{n}{f}\theta + \beta\right) + \sin\left(\frac{n}{f}\theta + \beta\right)\cos\theta\right].$$

Hence, by addition, we obtain the total voltage per phase of the rotor due to both fluxes—

$$2\,E_2\left(1 - \frac{n^2}{f^2}\right)\sin\left(\frac{n}{f}\theta + \beta\right)\cos\theta \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Since β is without effect on the virtual voltage, we may omit it, and write the volts per phase—

$$E_2\left(1 - \frac{n^2}{f^2}\right)\left(\sin\frac{f+n}{f}\theta - \sin\frac{f-n}{f}\theta\right) \quad . \quad . \quad . \quad . \quad (7)$$

When n has any finite value this will consist of two voltages having different frequencies but equal amplitudes. They will consequently have a resultant virtual value equal to $\sqrt{2}$ times the virtual value of either. Thus the virtual voltage per phase of the rotor will be—

$$v = E_2\left(1 - \frac{n^2}{f^2}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

It will also be evident from the previous consideration of the effect

of connecting two phases in star that, in a 3-phase star-connected rotor, the slip-ring voltage will have a value—

$$\sqrt{3}\,E_2\left(1-\frac{n^2}{f^2}\right),$$

which will have a virtual value of $\sqrt{2}\,E_2$ per phase when the motor is at rest, and the rotor is in the most favourable position.

The slip-ring voltage of the stationary star-connected rotor will be double this, or $2\sqrt{2}\,E_2$. The induced rotor phase voltage with short-circuited rotor is thus given for a $\frac{2}{3}$ wound stator by—

$$\frac{E_1}{\sqrt{2}\,\sqrt{3}\,k_3}\left(1-\frac{n^2}{f^2}\right),$$

while with a winding on only $\frac{1}{3}$ of the stator the corresponding voltage will be—

$$\frac{m\,E_1}{\sqrt{2}\,\sqrt{3}\,k_3}\left(1-\frac{n^2}{f^2}\right) \text{ volts per phase.}$$

E_1 represents in each case the applied stator voltage.

The "virtual stationary" voltage of the rotor is evidently the same whether the rotor circuit is open or closed (except for the loss of voltage in stator impedance).

Equivalence of Stator and Rotor Currents.

With a constant applied voltage at the stator terminals, the stator flux must remain constant (except for drop in the stator winding), and the resultant magnetomotive force of the stator circuit must consequently have the same value, at all speeds and for all values of the rotor currents. Accordingly, any rotor currents which are capable of producing a magnetomotive force along the axis of stator flux will be neutralised by a corresponding current in the stator winding. At any instant this added stator current will produce a number of ampere-turns equal and opposite to that due to the currents in the rotor along this axis.

Any revolving winding of the rotor which carries a current must evidently produce a magnetomotive force in various directions successively, and, unless the frequency of the current coincides with the frequency of rotation, the virtual value of the magnetomotive force due to the current will be the same in whatever direction it is measured. Such a current will consequently produce a magnetomotive force along the stator axis exactly equal to the magnetomotive force along any other axis. The stator winding will, however, receive an increase in current sufficient to neutralise this magnetomotive force along the stator axis. The magnetomotive force due to the rotor currents remains unneutralised along an axis perpendicular to this, although "compensation" due to rotation of the rotor occurs to raise the power factor at normal speeds. We thus see that the stator must always carry currents

which are the equivalent of all rotor currents, whether regarded as "magnetising" or not, and that, if the rotor has several phase windings, the stator will carry a current equal to the sum of the currents which would be required to balance the magnetomotive force of each phase separately. Each phase winding of the rotor may, in fact, be looked upon as giving rise to a magnetomotive force along the stator axis proportional to the current in it and the number of its turns. The fact that the space and phase displacements between the rotor windings are necessarily identical has the result that the magnetomotive forces due to all the coils have the same phase along any stator axis. In order to obtain the resultant effect along the stator axis the rotor currents are therefore to be added algebraically and not vectorially.

Suppose, for instance, that one rotor phase-winding of a 3-phase rotor carries $c_2 t_2$ ampere-turns. This will exert a magnetomotive force successively along all axes of the stator, the virtual value in any definite direction rising to a maximum of $c_2 t_2$ ampere-turns and falling to zero. When the rotation of the coil is sufficiently rapid to give steady readings of the neutralising stator current, the virtual stator ampere-turns indicated will be $\frac{1}{\sqrt{2}} c_2 t_2$ ampere-turns due to this phase, or $\frac{3}{\sqrt{2}} c_2 t_2$ ampere-turns balancing the three phases together.*

Numerical Value of Current Ratios.

With stationary short-circuited rotor, the currents in stator and rotor have the same relations as in the static transformer, so that in the position for maximum mutual induction we should obtain current ratios which are the reciprocals of the voltage ratios previously found, if we omit the constant stator magnetising current from our consideration. This position of the rotor will not, however, be the position giving the greatest ratio of rotor to stator current.

When in rotation, a stator wound over $\frac{1}{3}$ of its circumference will carry a current equal to $\frac{3}{\sqrt{2}} \frac{1}{k_3}$ times the current in each rotor phase because each rotor phase will exert a virtual magnetising force along the stator axis of $\frac{1}{\sqrt{2}} c_2 t_2$ ampere-turns, and the stator has to balance the ampere-turns of three phases. Hence, for this type of stator winding—

$$\frac{\text{rotor phase current}}{\text{stator current}} = \frac{\sqrt{2}\, k_3}{3}.$$

For stationary rotor and single-coil stator we find the current ratio to be the inverse of the ratio of voltages, so that—

$$\frac{\text{rotor phase current}}{\text{stator current}} = \frac{k_3}{m} \text{ (see page 208).}$$

* As shown on page 214, this statement must be modified by the introduction of the factor $\sqrt{3}$ for a stator with a winding extending over two-thirds of its circumference.

With a stator winding covering the arc occupied by two rotor phases we have as the stationary current ratio (for maximum mutual induction) the reciprocal of the stationary voltage ratio given on page 208, so that (approximately)—

$$\frac{\text{rotor phase current}}{\text{stator current}} = \frac{t_1}{t_2} = k_3 \text{ as for a 3-phase motor.}$$

When the rotor is in rotation, the stator current has to be the equivalent of $\frac{3}{\sqrt{2}}$ rotor amperes, as already explained. One ampere in the stator is, however, more effective than in the previous case because of the increased windings—in fact, the resultant magnetomotive force of 1 ampere in the $\frac{2}{3}$ winding will be $\sqrt{3}$ times as great along the stator axis as in the $\frac{1}{3}$ winding. We thus find the following ratio for the rotating rotor with a winding covering two-thirds of the stator :—

$$\frac{\text{rotor phase amperes}}{\text{stator amperes}} = \frac{\sqrt{2}\,k_3}{3} \times \sqrt{3} = \frac{\sqrt{2}}{\sqrt{3}}\,k_3.$$

Experimental Verification of Current Ratios.

The relations given in the previous section may be verified easily by short-circuiting the rotor winding through an ammeter, and supplying the stator with current at a low voltage. The magnetising current in the stator will be small and will tend to increase the ratio of stator to rotor current. The curves obtained in this way are shown in Fig. 2. The values of the currents were varied by driving the motor at different speeds. The actual observations gave the values shown by dots, while the lines show the theoretical ratios as given in the previous section, to which the observed values approximate, and with which they would coincide if it were not for the stator magnetising current. Besides the ratios for the motor when running, the current ratios obtained with the rotor stationary and in the position for maximum mutual induction are plotted. A curve taken with the motor supplied with 3-phase current and run at various speeds is also shown.

It is evident from the curves in Fig. 2 that (as in the case of the voltage ratios) there is a definite ratio between stator and rotor currents when the motor is running, and another definite ratio when the motor is at rest, and in the position of maximum mutual induction. There is no gradual change of one ratio into the other as the speed changes. This appears to be contrary to the statement of Steinmetz,* which suggests a gradual change as the speed of the motor alters from zero to synchronism.

Connection between Current and Voltage in Rotor.

In obtaining the expressions for the rotor voltage as given in equations (7) and (8) we have neglected the effect of rotor

* "Alternating Current Phenomena," 4th ed., p. 329.

resistance and leakage reactance in diminishing the perpendicular component of the flux. Assuming this to be permissible for practical purposes, we ought to be able to obtain the magnitude of the rotor current by dividing the theoretical value of the rotor voltage by the impedance of the rotor winding. Since the impedance of the rotor will vary with the speed of the motor, it will be necessary to ascertain the law according to which it varies with the speed.

Impedance of Rotor Winding.

The impedance will consist of two elements—viz., the resistance

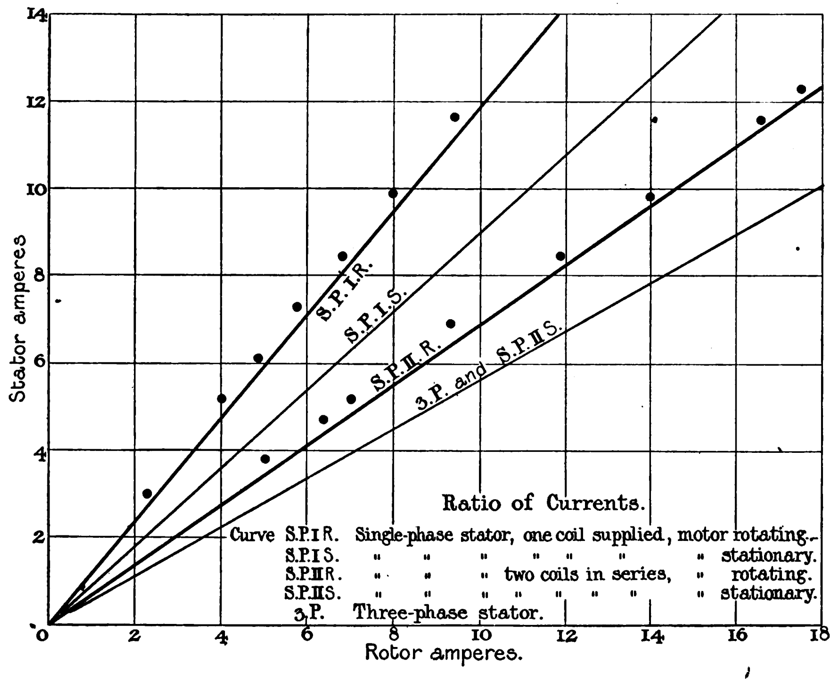


FIG. 2.

having a constant value, and the leakage reactance, which will vary with the speed.

We have shown that the induced rotor voltage may be looked upon as composed of two component voltages, equal in amplitude, but having frequencies of $f+n$ and $f-n$ respectively (see equation (3), page 205). Because these voltages are of differing frequencies they will act independently on the reactance of the rotor circuit, so far as the production of current is concerned, and the circuit will offer the same resistance but a different reactance to each.

Thus, calling the two component voltages e_1 and e_2, e_1 will give rise to a current—

$$c_1 = \frac{e_1}{\left[r_2^2 + \left(2\frac{f+n}{f}x_2\right)^2\right]^{\frac{1}{2}}}$$

where—

r_2 denotes the resistance of the winding

and—

x_2 denotes the reactance of the winding at a frequency f.

Similarly e_2 will produce a current—

$$c_2 = \frac{e_2}{\left[r_2^2 + \left(2\frac{f-n}{f}x_2\right)^2\right]^{\frac{1}{2}}}.$$

Since $c_1 + c_2 = c$ will be the total current in the winding, we may consider the rotor circuit as being equivalent to a single resistance

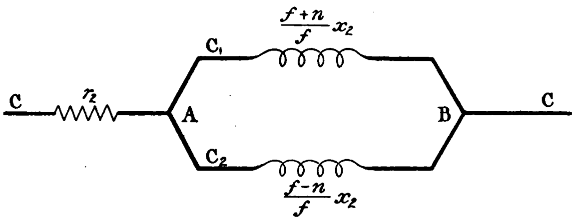


FIG. 3.—Equivalent Circuits of Rotor.

connected in series with a reactance composed of two parallel unequal parts, as indicated in Fig. 3.

The admittance of the part of the circuit between A and B will have a value—

$$\frac{1}{2x_2}\frac{f}{f+n} + \frac{1}{2x_2}\frac{f}{f-n} = \frac{1}{x_2}\frac{f^2}{f^2-n^2}$$

and the joint impedance of this part of the circuit will be—

$$x_2\frac{(f^2-n^2)}{f^2}.$$

The impedance of the rotor winding is consequently—

$$z = \sqrt{r_2^2 + \left(x_2\frac{f^2-n^2}{f^2}\right)^2},$$

hence we have—

$$c_2 = \frac{v_2}{\sqrt{r_2^2 + x_2^2\left(\frac{f^2-n^2}{f^2}\right)^2}} \quad \ldots\ldots\ldots \quad (9)$$

We have already found the value of the induced rotor voltage per

phase on the assumption of no losses in the stator winding to be —see equation (8)—

$$v_2 = \mathrm{E}_2\left(1 - \frac{n_2}{f^2}\right),$$

where E_2 is the "virtual stationary" voltage induced.

The relation between the voltage E_2 and the rotor current is consequently given by—

$$c_2 = \frac{\mathrm{E}_2\left(1 - \frac{n^2}{f^2}\right)}{\sqrt{r_2^2 + x_2^2\left(1 - \frac{n^2}{f_2}\right)^2}}$$

$$= \frac{\mathrm{E}_2}{\sqrt{r_2^2\left(\frac{f^2}{f^2 - n^2}\right)^2 + x_2^2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

If the applied stator voltage is assumed constant, we shall have a loss in the stator winding tending to diminish the value of E_2. Adopting the usual vector notation, we may write the applied voltage—

$$\mathrm{E}_1 = k_e \mathrm{E}_2 + \mathrm{C}_1(r_1 - j\,x_1) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

where C_1 is the stator current and $(r_1 - j\,x_1)$ represents the primary impedance due to resistance and leakage reactance.

Neglecting the magnetising current—

$$\mathrm{C}_1 = \frac{1}{k_c}\mathrm{C}_2.$$

Also, the secondary voltage E_2 may be expressed in terms of the rotor current by making use of equation (10) converted into vector form; thus—

$$\mathrm{E}_2 = \mathrm{C}_2\left(r_2\frac{f^2}{f^2 - n^2} - j\,x_2\right).$$

Hence, except for magnetising current—

$$\frac{\mathrm{E}_1}{k_e} = \mathrm{C}_2\left[r_2\frac{f^2}{f^2 - n^2} + \frac{1}{k_e k_c}r_1 - j\left(x_2 + \frac{1}{k_e k_c}x_1\right)\right] \quad . \quad . \quad (12)$$

Now $\frac{\mathrm{E}_1}{k_e}$ is the open-circuit "virtual stationary" voltage per phase of the rotor, so that equation (12) gives the relation between this constant voltage and the current of the motor at any speed.*

The numerical form of the relation just given is—

$$c_2 = \frac{\mathrm{E}_2}{\sqrt{\left(r_2\frac{f^2}{f^2 - n^2} + \frac{1}{k_e k_c}r_1\right)^2 + x^2}} \quad . \quad . \quad . \quad . \quad . \quad (13)$$

* Compare the vector equations for the single-phase motor given in "Vectors and Vector Diagrams," by Cramp and Smith, published by Longmans & Co.

where x is written for the reactance of both windings referred to the rotor circuit.

In order to verify the accuracy of this formula for practical purposes, tests were made on a number of motors by driving them at

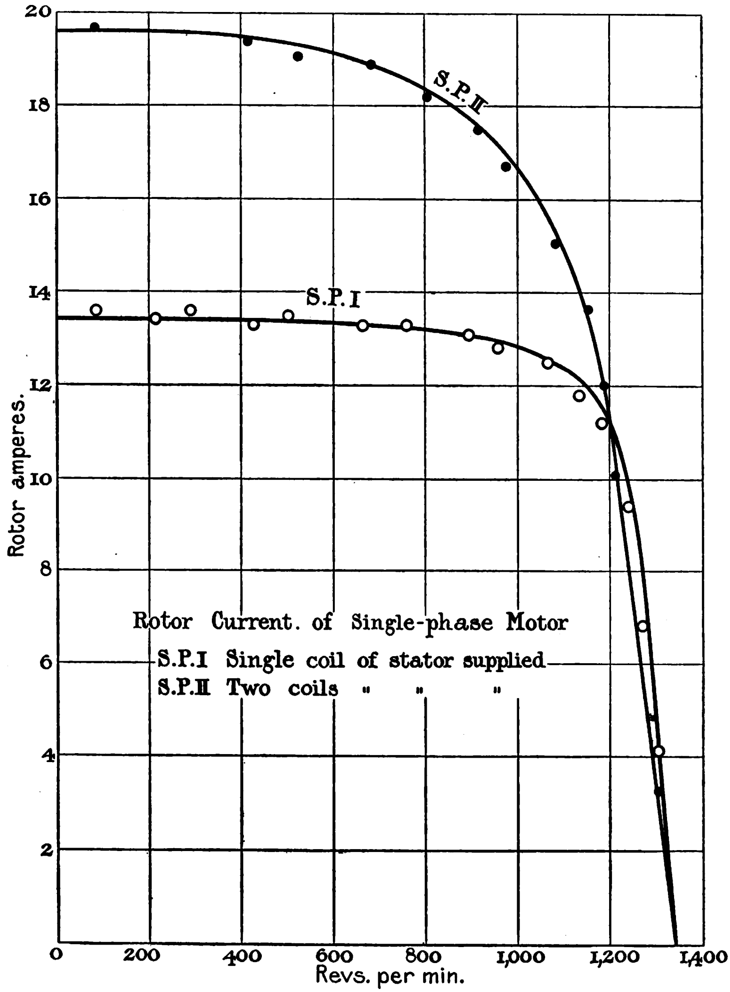


FIG. 4.

various speeds with short-circuited rotor, while a constant low alternating voltage was applied to the stator. The rotor current was observed and plotted on a base of speed as shown in Fig. 4. By substituting the measured values of the stator and rotor resistance

in equation (13) the reactance of the motor was determined for the condition when $n=0$, and a calculated curve of current for different speeds (shown by the lines in Fig. 4) was obtained. The agreement between the calculated and observed values (the latter shown by dots and circles) is quite as close as could be expected.

The value of E_2 employed in the calculation of the current was obtained directly from the open-circuit curve (see Fig. 1), since the value of E_2 when $n=0$ will be the same whether the rotor circuit is open or closed.

Calculation of Equivalent Resistance.

Let—

$k_c =$ Ratio of rotor phase current to stator current (omitting stator magnetising current).

$k_e =$ Ratio of stator voltage to rotor phase voltage ("virtual stationary value").

$r_1 =$ Resistance of stator winding.

$r_2 =$ Resistance of rotor winding per phase.

The equivalent resistance of the motor windings referred to the rotor circuit will then have the value—

$$R_2 = r_2 + \frac{1}{k_c k_e} r_1;$$

similarly the equivalent resistance of both windings referred to the stator would be—

$$R_1 = r_1 + k_c k_e r_2.$$

Applying this to the case of our motor, we have—

$r_1 = 0{\cdot}25$ ohm for single coil supplied,

or—

$0{\cdot}5$ ohm for two coils supplied in series.

$r_2 = 0{\cdot}11$ ohm.

With 2-coil stator—

$$k_c = \frac{\sqrt{2}}{\sqrt{3}} k_3 = 1{\cdot}45,$$

$$k_e = \sqrt{3} \cdot \sqrt{2} \cdot k_3 = 4{\cdot}36.$$

Hence for this case—

$$R_2 = 0{\cdot}11 + \frac{0{\cdot}5}{1{\cdot}45 \times 4{\cdot}36} = 0{\cdot}19 \text{ ohm}.$$

With single-coil stator—

$$k_c = \frac{\sqrt{2}}{3} k_3 = 0{\cdot}84,$$

$$k_e = \frac{\sqrt{2} \ \sqrt{3}\, k_3}{m} = 2{\cdot}74;$$

consequently—

$$R_2 = 0{\cdot}11 + \frac{0{\cdot}25}{0{\cdot}84 \times 2{\cdot}74} = 0{\cdot}219,$$

we may call the factor $k_c\, k_e$ the "impedance ratio" of the single-phase motor, corresponding to k_3^2 for the 3-phase motor.

In conclusion, it may be convenient to add in tabular form a list of the voltage, current, and impedance ratios for the two cases of a stator winding embracing $\frac{2}{3}$ of the stator circumference and for a winding of half this width.

Table of Ratios.

Stator Winding.	Stator Volts / Rotor Phase Volts		Rotor Phase Current / Stator Current		Rotor Impedance / Equivalent Stator Impedance
	Stationary.	Rotating.	Stationary.	Rotating.	
Three-phase (stator volts per phase)	k_3	—	k_3	—	k
Single-phase, $\frac{2}{3}$ stator winding ...	k_3	$\sqrt{3}\ \sqrt{2}\ k_3$	k_3	$\frac{\sqrt{2}}{\sqrt{3}}\, k_3$	$2\, k_3^2$
Single-phase, $\frac{1}{3}$ stator winding ...	$\frac{1}{m}\, k_3$	$\frac{\sqrt{2}\ \sqrt{3}}{m}\, k_3$	$\frac{1}{m}\, k_3$	$\frac{\sqrt{2}}{3}\, k_3$	$\frac{2}{\sqrt{3}\, m}\, k_3^2$

The value of m appears to be about 1·6 for the usual distribution of winding covering one-third of the stator circumference.

The author has to thank his colleague, Mr. W. Grant, for assistance in connection with the experiments made for this paper. The experimental work was carried out in the Electrical Engineering Laboratories of the Municipal School of Technology, Manchester, and the motors employed belong to the equipment of the Electrical Engineering Department of the School.

List of Symbols Employed.

c_1 Stator current in amperes.

c_2 Rotor current in amperes.

E_1 Stator applied voltage.

E_2 "Virtual stationary" rotor voltage per phase.

f Frequency in cycles per second.

k_3 Ratio of stator phase voltage to rotor phase voltage of stationary 3-phase motor $\left(=\frac{t_1}{t_2}\right)$.

k_c Ratio of rotor phase current to stator current (omitting stator magnetising current).

k_e Ratio of stator voltage to rotor phase voltage of single-phase motor

m A constant giving the relation between k_3 and k_e $\left(k_e = \frac{k_3}{m}\right)$ employed in the case of stator wound over one-third of circumference.

n Frequency of rotation = revs. per second of rotor × number of pole-pairs of stator.
r_1, r_2 Resistance of stator and rotor phase winding.
t_1, t_2 Number of turns in stator and rotor phase.
v Instantaneous value of voltage induced in rotor coil.
x_1, x_2 Leakage reactance of stator and rotor phase winding.
α Angle between plane of rotor coil and axis of stator flux.
β A constant angle.
ϕ Instantaneous value of stator flux.
Φ Maximum value of stator flux.

ORIGINAL COMMUNICATION.

THE PRODUCTION, MEASUREMENT, AND EFFECT OF VARIABLE WAVE-FORM.

By LANCELOT W. WILD, Member.

(*Received August* 3, 1909.)

In the course of everyday testing, discrepancies sometimes arise in the results obtained in different laboratories. In the case of alternating-current tests such discrepancies are often attributed to differences of wave-form, without those concerned having any clear idea as to what the effect of wave-form may be in the matter in dispute.

In order to be able to demonstrate when called upon, to what extent wave-form may affect any particular apparatus, I have made arrangements in my laboratory for varying the wave-form over wide ranges.

In this paper I shall describe first the means by which I vary the wave-form, and secondly the means I have adopted for measuring its essential characteristics. Finally, I present the results of some tests carried out with the idea of indicating the sort of effect that may be expected with various apparatus when the wave-form is varied.

THE PRODUCTION OF VARIABLE WAVE-FORM.

The ideal method of varying wave-form at will is to couple up several alternators, each separately excited and running at different frequencies. The first of these might run at 50 periods and generate the fundamental sine wave, the second at 150 and generate the third harmonic, and so on. At the National Bureau of Standards, Washington, they have such an arrangement.* The alternators are separately excited, and are arranged so that their shaft couplings can be shifted, so that not only can the amplitude of the harmonics be varied, but also their phases with respect to the fundamental. All the odd harmonics up to the fifteenth can thus be added to the wave, and at any desired phase displacement.

* *Bulletin of the Bureau of Standards*, vol. 4, p. 496, 1907.

This method of producing variable wave-form was not at my disposal, so I have had to do the best I could with a single alternator, the armature of which is wound with three sets of coils.

This machine was originally a 6-pole direct-current machine of about 1½-k.w. capacity. The armature is furnished with 7 slots per pole. The armature was rewound with 3 sets of coils and the commutator replaced by 5 collector rings.

One winding occupies the two outer pairs of slots, and gives on open circuit a flat-topped wave. This winding will be called F.

The second winding occupies the next three pairs of slots inside F and gives a peaked wave. This winding is known as P.

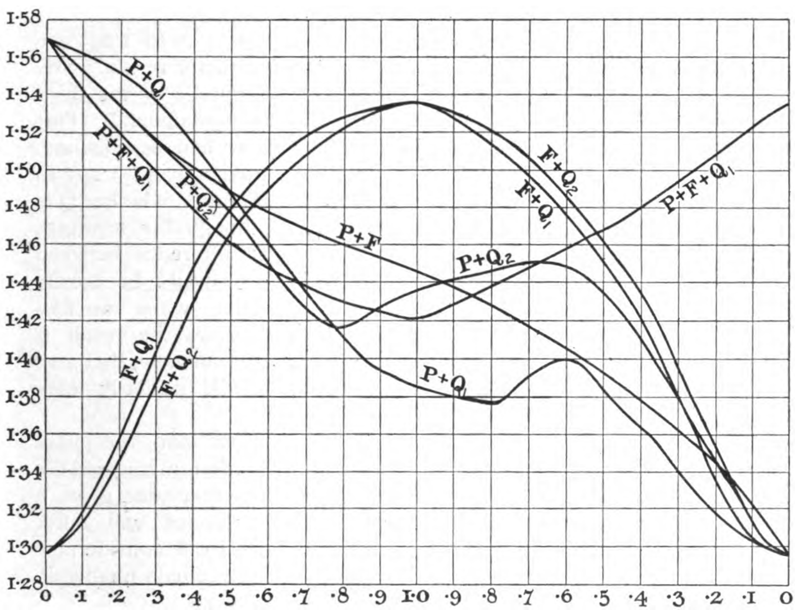


FIG. 1.

The remaining slots are occupied by a winding similar to F but in quadrature with it. This is designated Q_1 or Q_2 according to whether it is connected to lead or lag with regard to P or F.

From these three original waves some hundreds can be built up—peaked, flat, dimpled, symmetrical, and unsymmetrical. The waves are built up by combining the original waves in various proportions, the proportioning being effected by means of transformers.

By adding together P and F a series of symmetrical waves are produced from peaked to flat, according to the mixture. By subtracting a portion of P from F, a set of dimpled waves are produced—that is to say, waves with a double peak. By taking a portion of F from P a

set of very peaked waves are produced, the greater part of the rise of the wave being concave instead of convex as usual.

F and Q_1 or F and Q_2 give a series fairly symmetrical, yet differing greatly from the P F series.

P and Q_1 and P and Q_2 give two series of extremely unsymmetrical waves.

Fig. 1 shows the range of amplitude factors obtainable. The ordinates of these curves are amplitude factors, and the abscissæ represent the proportion of the mixture. Thus at the figure 0 one winding only is employed, at 0·5 half the voltage of the second winding is added, at 1·0 the whole of the voltage of the second winding is added, and at the second 0 the voltage of the first winding is brought down to zero.

With the P + F series amplitude factors from 1·57 to 1·295 are produced. With all F and 0·67 P the amplitude factor is $\sqrt{2}$. The resulting wave is an almost perfect sine, the amplitude of the third harmonic being only about 1 per cent. of the fundamental. This is the only mixture by means of which a sine wave can be obtained.

The F Q_1 and F Q_2 series give amplitude factors from 1·295 to 1·535. It will be noticed that it makes some difference whether Q is connected to lead or lag with regard to F. Although the windings are supposed to be similar, yet there is a slight difference between the waves they generate, though the difference would be hardly apparent on an oscillogram. It should be noted that when two flat-topped waves in quadrature are connected in series the result is a peaked wave. The converse would also be true—namely, that two peaked waves would produce a flat-topped one if similarly connected.

Suppose a meter has to be tested on an inductive load, the phase being adjusted by means of a 2-phase phase-shifter acting on the pressure circuit. It is apparent that unless the alternator gives a sine wave the voltage wave supplied to the meter will differ from the original wave of the circuit, sometimes by a considerable amount. The current wave, on the other hand, will remain unaltered. If, now, instead of using the phase-shifter the phase difference is produced by using a choking coil in the current circuit, the voltage wave will remain unaltered and the current wave will be affected, which is more like the conditions which the meter will have to experience in service. A phase-shifter should therefore be employed with caution if the wave-form differs widely from the sine form.

The P Q_1 and P Q_2 series are somewhat remarkable. Adding Q to P at first lowers the amplitude factor, but afterwards the curves rise again for a time before they finally fall. Also it will be noticed that with some mixtures it makes a considerable difference whether Q is leading or lagging with regard to P.

So far the author has only dealt with mixtures of two windings. By mixing the voltage from all three windings many more waves can be produced. For example, if P is mixed with F and Q_1, F and Q

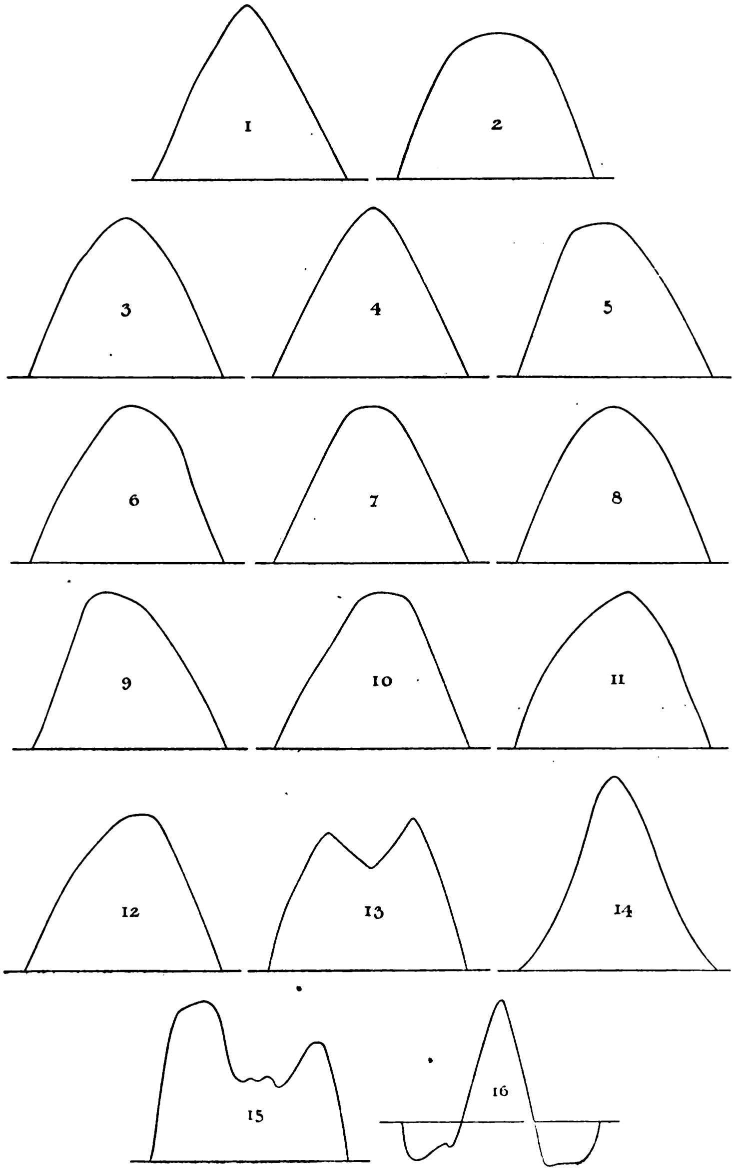


FIG. 2.

being varied as one unit, amplitude factors from 1·57 down to 1·42 and then up again to 1·535 are produced.

It will be noticed from these curves that an amplitude factor of $\sqrt{2}$ can be produced in no less than nine different ways. Only one of these, however, produces a sine wave, and some of the other waves though having the same factor as a sine wave yet have very different effects upon some classes of apparatus.

To investigate thoroughly all the waves obtainable from this alternator would be the work of years; the author has accordingly contented himself with standardising sixteen waves for present use. These are delineated in Fig. 2.

Amongst the symmetrical waves No. 1 has the highest and No. 2 the lowest amplitude factor. These are P and F respectively. No. 3 is F + Q_1, and has rather a high amplitude factor. No 4 is P + F, and is rather more peaked than a sine wave.

Waves 5 and 6 are P Q_1 and P Q_2 respectively. They are both unsymmetrical. Altering Q from leading to lagging not only considerably alters the shape of the wave, but also alters the amplitude factor from 1·385 to 1·435, and the mean ordinate factor from 0·894 to 0·896.

Waves No. 7 to 12 all have amplitude factors of $\sqrt{2}$. No. 8, however is the only one resembling a sine. Their mean ordinate factors vary from 0·888 for 7, 9, and 10 to 0·908 for No 11, which is sufficient to make about 4 per cent. difference in the hysteresis loss of a transformer working at 10,000 nominal $B_{max.}$ or over.

No. 13 is a dimpled wave produced by taking a portion of P from F. No. 14 is the converse of No. 13. Taking a portion of F from P scoops a bit out of the sides.

No. 15 is produced by opposing P to F and adding Q. It has an extremely high mean ordinate factor combined with rather a high amplitude factor.

No. 16 is the most curious wave of all. This is produced by opposing P to F without any transformation. The wave may be regarded in three ways: It is a highly peaked wave with dips below zero at start and finish; it is a dimpled wave with dimple going right below zero; or it is a wave of triple frequency containing even harmonics.

In Table A will be found particulars of the waves, their amplitude and mean ordinate factors, and their mixture formulæ.

The alternator has only a small output—namely, 10 amperes at 60 to 130 volts according to wave-form at 50 periods. If the standard waves are to be maintained, it is necessary to avoid taking anything like full load from the machine, as it has been ascertained that loading the machine affects the wave-forms.

In Table B is shown the effect of loading the machine. The amplitude factors of the waves at half-load are altered from 1 to 3 per cent.

Table C shows the effect of altering the field strength of the machine. At half-volts the amplitude may alter as much as 2 per cent.

Periodicity has no effect upon amplitude factor on open circuit.

In carrying out tests of precision it is necessary so to arrange matters with transformers that the field has not to be varied over wide limits, and the load actually put upon the machine is as small as possible.

In carrying out the tests following the load on the machine has been kept down to half an ampere as a maximum, and except for

TABLE A.

Characteristics of Standard Waves.

Wave No.	Amplitude Factor.	Mean Ordinate Factor.	Formula.
1	1·570	0·872	P
2	1·295	0·914	F or Q
3	1·445	0·895	P F
4	1·535	0·878	F Q_1
5	1·385	0·894	P Q_1
6	1·435	0·896	P Q_2
7	1·420	0·888	P F Q_1
8	1·415	0·900	F 67 per cent. P
9	1·415	0·888	P 78 per cent. Q_1
10	1·415	0·888	P 78 per cent. Q_2
11	1·420	0·908	Q 44 per cent. P
12	1·415	0·899	F 33 per cent. Q_1
13	1·390	0·902	F—50 per cent. P
14	1·790	0·845	P—50 per cent. F
15	1·470	0·945	F—P + 33 per cent. Q_1
16	2·220	0·875	F—P

the tests for dielectric strength the field has not been altered more than about 5 per cent.

THE MEASUREMENT OF AMPLITUDE FACTOR.

In carrying out the foregoing tests some 200 amplitude factors have had to be measured accurately to within about ¼ per cent. To

have obtained these figures from a study of the waves themselves would have involved the expenditure of an immense amount of

TABLE B.

Effect of Load on Amplitude Factor.

Formula.	Amplitude Factor.		
	Open Circuit.	5 Amperes, Non-inductive.	5 Amperes, 0·5 Power Factor.
P ...	1·570	1·560	1·570
F ...	1·295	1·310	1·275
P F ...	1·445	1·430	1·400
P Q_1 ...	1·385	1·360	1·370
F Q_1 ...	1·535	1·525	1·530
P F Q_1	1·420	1·425	1·395

TABLE C.

Effect of Field Strength on Amplitude Factor.

Formula.	Half Volts.	Full Volts.
P	1·600	1·570
F	1·260	1·295
P F...	1·445	1·445
P Q_1.	1·385	1·385
P Q_2	1·425	1·435
F Q_1	1·550	1·535
F Q_2	1·550	1·535
P F Q_1	1·420	1·420
P F Q_2	1·425	1·425

time, and the figures finally obtained would not have been so accurate as the author obtained by the following method :—

The alternator was coupled by a belt to another machine, the

pulleys being of equal diameter. On a second pulley of the auxiliary machine was fixed a contact-maker, arranged to operate for a brief period once in every revolution.

The circuit was made up as in Fig. 3. V is an electrostatic voltmeter shunted by a couple of condensers C C. S_1 is a switch for short-circuiting the contact-maker. S_2 is a two-way switch for switching over on to direct current for testing the efficacy of the contact-maker.

With S_1 open and S_2 on right-hand contact the condensers are charged once in every revolution, and the voltmeter registers the instantaneous value of the voltage at the instant at which contact is broken.

If the pulleys are exactly similar, and there is no belt slip, the condensers will be charged always at one point of the wave. The slightest belt slip will, however, cause precession to take place, so that the voltmeter spot will never be at rest, but will move slowly up and down its scale from zero up to the maximum point of the wave.

By adjusting the tightness of the belt the voltmeter spot may be made to move faster or more slowly as desired. The author has found

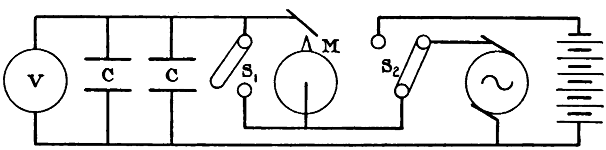


FIG. 3.

no difficulty in so adjusting the belt as to lengthen the time taken for the voltmeter to go through a half-period to 10 minutes. When the object is only to record the maximum point of the wave a quicker movement than this is preferable, say half a period in 1 minute.

In making a test for amplitude factor the procedure is as follows:—

After the belt slip has been adjusted to give a convenient speed to the voltmeter spot, S_2 is switched over to the left. The voltmeter is then on direct current. S_1 is then closed and opened again. The same reading should be obtained on the voltmeter whether S_1 is open or closed. If the reading is lower when S_1 is open, either the insulation resistance of the voltmeter, condensers, and leads are too low, or else the contact-maker is misfiring. The trouble must then be sought out and remedied, for otherwise the voltmeter will not register the true peak of the wave when switched on to alternating current.

When it is ascertained that everything is working properly, S_2 is switched over to the right, S_1 being open. The voltmeter will then register the ordinates of the wave. The maximum reading is noted, then the switch S_1 is closed, and the R.M.S. voltage read off on the same voltmeter. S_1 is then opened again, and as the spot comes up the scale the maximum is again read—this time on the other half of the wave. The mean of the two maxima should be taken, as thus con-

tact force is eliminated from the measurement. The maximum ordinate divided by the R.M.S. voltage gives one the amplitude factor.

It is well to make tests with first one and then two condensers. In this way one obtains an alternative way of detecting any misfiring of the contact-maker or leakage between the periods of contact.

The voltmeter which I have been using can be read with an accuracy of 1 part in 1,000. The spot on steady voltage comes to rest in 10 seconds. In making tests for amplitude factor I have always had the belt slip so adjusted as to cause the spot to take at least 80 seconds to pass through a half-period. The accuracy of the measurement should be, therefore, well within the $\frac{1}{4}$ per cent. aimed at.

At first considerable difficulty was experienced in obtaining a satisfactory contact-maker. The type eventually adopted is shown in Fig. 4. P is a revolving drum—in this case a pulley. K, the striker, is made from a brass stud, and is filed to a knife-edge. S is a very light clock spring clamped between a back plate B and a damping plate D. D protrudes to within $\frac{1}{8}$ inch of the end of S. As the spring rebounds after being

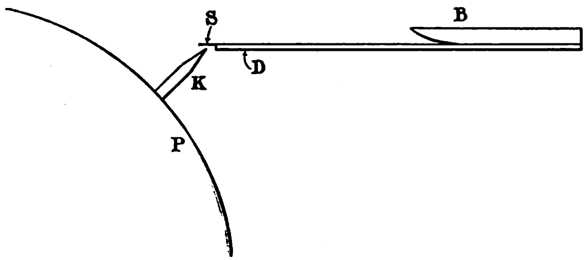


FIG. 4.

struck it hits against the damping plate and all vibration is damped out before the striker comes round again. Thus the striker always finds the spring at rest, the contact is always of the same duration, and the make and break are always made at the same exact point of the revolution.

THE DELINEATION OF WAVE-FORM.

The same arrangement as employed for the measurement of amplitude factor could also be used for plotting out waves. It suffices to take readings of the voltmeter at equal intervals of time, and then the wave can be plotted out. However, with an electrostatic voltmeter having a square law scale there is some difficulty in arriving at the exact instant of the zero, and I have therefore found it better to modify slightly the arrangement for plotting the waves. The arrangement of the circuit is shown in Fig. 5. The chief alteration is that a battery of accumulators is permanently connected in series with the voltmeter, so that the zero of the wave comes some way up the scale into a position where the voltmeter is fairly sensitive.

The mode of procedure is as follows:—

S_2 is switched to the left, cutting out the alternator, and readings are taken with S_1 closed and open. The reading thus obtained fixes the zero of the wave. S_2 is then turned to the right, and S_1 is opened. As the voltmeter spot passes through the false zero a stop-watch is started, and then readings are taken of the ordinates every 10 seconds. As the spot passes a second time through the false zero the watch is stopped and the odd seconds noted. The number of degrees and fractions of a degree corresponding to each 10 seconds is then calculated, and the ordinates are then plotted out on sectional paper.

The author's practice is to go through each wave 3 times and plot the points on the same paper. Taking about 200 seconds per half-wave about 60 points are thus obtained. The wave is then drawn passing through as many points as possible. Generally speaking, no point falls more than 1° off the wave as finally drawn.

Greater precision might be obtained by replacing the belt drive by suitable gearing, arranged to give a difference of speed between the two shafts of 1 part in, say, 50,000. The author has not, however, thought it necessary to go to this expense, as the waves obtained with the belt drive are sufficiently accurate for his purpose, the object being to

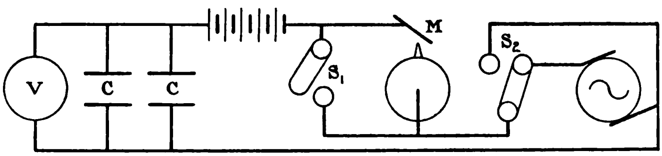


FIG. 5.

obtain a picture showing the type of the wave rather than an exact representation from which the harmonics could be calculated with a very high degree of exactness.

THE MEASUREMENT OF MEAN ORDINATE FACTOR.

A knowledge of amplitude factor is useful, but for many purposes the mean ordinate factor is of much greater importance. Mean ordinate factors do not vary through anything like the same range as amplitude factors, and consequently a higher degree of accuracy is demanded in their measurement.

By the following means the author believes that he has secured an accuracy of to 1 part in 1,000 in the measurement of his mean ordinate factors.

If a direct-current moving-coil voltmeter is connected to an alternating-current circuit it registers, not the R.M.S. voltage, but the algebraic mean of the wave. This ordinarily is zero. If, however, a rectifier is connected in series so as to reverse connections at the zero of the wave, the voltmeter will correctly register the mean ordinate of the half-wave.

All one requires, then, to measure mean ordinates is a moving coil voltmeter, a rectifying commutator, and an eloctrostatic voltmeter. Inasmuch as it is difficult to set the brushes of the rectifier to commutate exactly at zero, the author puts his rectifier on a separate shaft driven by a slipping belt as employed for the measurement of amplitude factor. The voltmeter needle then moves up and down the scale, the maximum reading obtained when multiplied by the constant of the instrument being the mean ordinate of the E.M.F. wave.

Fig. 6 shows the manner of connecting up. C is the rectifier. V is an electrostatic voltmeter. R is a non-inductive non-capacious resistance. G is a direct-current moving-coil galvanometer.

In order that the highest accuracy possible may be obtained, the galvanometer is calibrated against the electrostatic voltmeter as a standard.

The mean ordinate of the E.M.F. wave is read off from the maximum reading of the galvanometer and the R.M.S. value of the wave from the electrostatic voltmeter. The ratio of these two gives the mean ordinate factor.

If readings are taken on the galvanometer at equal time intervals

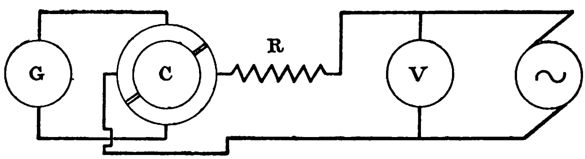


FIG. 6.

one obtains the ordinates of the B wave corresponding to the E.M.F. wave. There is, however, some danger that an error may be made due to the missing out of a portion of the integration of the E.M.F. when commutation does not take place at the zero of the E.M.F. wave. I should prefer to calculate B waves from E.M.F. waves determined in some other manner.

THE EFFECT OF WAVE-FORM ON THE LOSSES IN TRANSFORMER IRON.

It is commonly stated that the loss in transformer iron is less for a peaked than for a flat-topped wave. This is not always true. The loss depends not upon the amplitude factor, but upon the mean ordinate factor of the wave, and although a high amplitude factor is generally accompanied by a low mean ordinate factor the two are not inseparably connected, as witness wave No. 15, which has a rather high amplitude factor and an extremely high mean ordinate factor.

Messrs. Joseph Sankey & Sons kindly supplied three samples of transformer iron labelled Armature, Lohys, and Stalloy, for the tests for the effects of wave-form. The general data of these samples are given in Table D.

The samples were built up into magnetic squares with interleaved butt joints as in ordinary transformer construction, and were tested by a wattmeter method at various inductions and frequencies for loss on varying waves.

The coils were wound on formers fixed to a baseboard, all that was required to prepare for a test being to thread in the stampings and connect up the various circuits.

Fig. 7 shows diagrammatically the magnetic square and its circuit connections. The magnetising coil M consists of a single layer of No. 14 wire wound all round the square and as close in to the corners as circumstances would permit.

Over this coil is wound a second coil S also wound all round the square. This coil supplies current to the wattmeter pressure circuit, R

TABLE D.

Transformer Iron Tests. General Data.

	Armature.	Lohys.	Stalloy.
Number of stampings...	200	192	192
Weight in pounds ...	5·44	5·25	5·39
Specific gravity ...	7·88	7·61	7·52
Thickness, in inches ...	0·0136	0·0142	0·0148
Length of stampings ...	7 in.	7 in.	7 in.

being a non-inductive non-capacious resistance and P the moving coil of the wattmeter.

A set of four fine wire coils, each of 500 turns, is wound over all, and one or more sections of these as required are connected to the electrostatic voltmeter V.

Current is supplied to the magnetising coil by an auto-transformer T. The ratio of this transformer can be varied as required, the alternator field being only altered to obtain the final fine adjustment.

The wattmeter reads the watts consumed in the iron plus the watts consumed in the pressure circuit. The watts consumed in the current coil of the wattmeter and the magnetising coil of the square are excluded from the measurement. The amount to be deducted for the watts taken by the wattmeter shunt is readily calculated from the voltmeter reading and the known resistance of the pressure circuit.

The value of nominal $B_{max.}$ is calculated by the usual formula—

$$\text{Nominal } B_{max.} = \frac{\sqrt{2} \times V \times 10^6}{2\pi \times \sim \times T \times A}.$$

where A is the area of iron in square centimetres, V is the voltage, T is the number of turns on voltmeter coils.

The true $B_{max.}$ is found by multiplying the nominal $B_{max.}$ by the mean ordinate factor of the wave and divided by 0·900 the mean ordinate factor of a sine wave.

The wattmeter employed for these tests was a reflecting deflectional instrument of the dynamometer type, with bifilar suspensions 15 in. long and ¼ in. apart.

The instrument is furnished with resistances giving ranges of 10, 30, and 100 watts. Most of the tests were made on the 10-watt range, the 30-watt range being occasionally required.

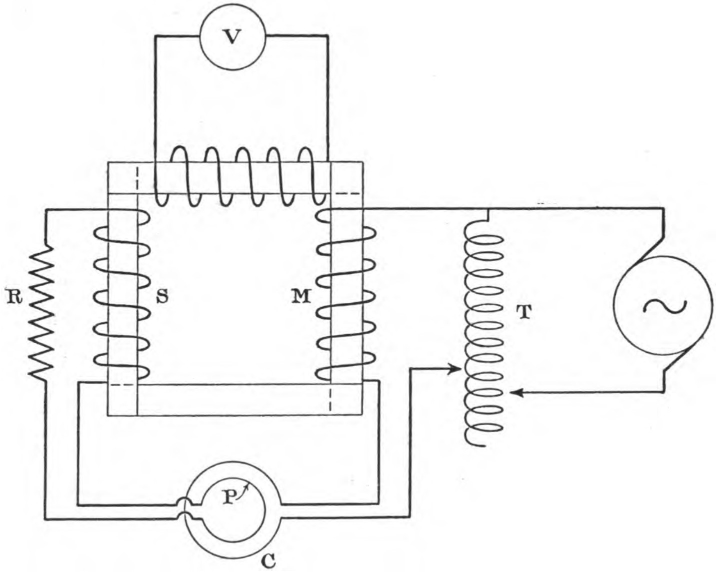


FIG. 7.

At 10,000 $B_{max.}$ and 50 periods, the wattmeter pressure circuit consumes about 0·2 watt, generally about 5 per cent. of the loss in the iron. The error introduced by the self-induction of the wattmeter coil is 0·5 per cent. on 0·4 power factor and 50 periods on the 10-watt range.

The control is sufficiently strong to prevent the shifting of the zero of more than 1 part in 1,000 after 1 hour's deflection to the top of the scale.

The drop in the alternator, transformer, series coil of wattmeter, and magnetising coil amounts to about 1 per cent. at 10,000 B and 50 periods. This amount of drop would not seriously affect the wave-form.

A wattmeter for testing small quantities of transformer iron is of

necessity a compromise. One requires both shunt and series losses to be small on the one hand ; and, on the other hand, one requires as large a control as possible and a minimum of self-induction in the pressure circuit.

Table E.

Transformer Iron Tests at 50 Periods on Waves Nos. 1 and 2.

Nominal B_{max}	Watts per Lb.					
	Armature.		Lohys.		Stalloy.	
	No. 1.	No. 2.	No. 1.	No. 2.	No. 1.	No. 2.
2,500	0·122	0·131	0·113	0·122	0·0650	0·0705
	1·65	1·65	1·70	1·70	1·70	1·70
5,000	0·386	0·415	0·373	0·392	0·2145	0·2320
	1·65	1·65	1·70	1·70	1·65	1·65
7,500	0·753	0·810	0·741	0·787	0·4200	0·4570
	1·65	1·65	1·70	1·70	1·70	1·70
10,000	1·220	1·310	1·205	1·285	0·6850	0·7430
	1·80	1·80	1·75	1·85	1·75	1·85
12,500	1·790	1·952	1·787	1·944	1·0180	1·1200
	1·90	1·95	2·00	2·10	1·80	1·80
15,000	2·540	2·780	2·570	2 840	1·4100	1·5600

In Table E is given the loss in watts per pound for the three samples on waves 1 and 2 at 50 periods and at various values of nominal $B_{max.}$ The figures between the lines are the exponents. Thus for

Table F.

Transformer Iron Test. Percentage difference in Total Loss on Waves 1 and 2 at 50 Periods and various Values of Nominal $B_{max.}$

Nominal $B_{max.}$	Armature.	Lohys.	Stalloy.
2,500	7·4	7·9	8·5
5,000	7·5	5·1	8·2
7,500	7·6	6·2	8-8
10,000	7·4	6·6	8·5
12,500	9·1	8·8	10·0
15,000	9·5	10·5	10·6

armature iron the total loss exponent is 1·65 up to 10,000 $B_{max.}$, increasing to 1·9 between 12,500 and 15,000. The exponent for Lohys is 1·7 at the lower inductions increasing to 2 or 2·1 at the highest.

Table G.

Test at 50 Periods and 10,000 Nominal $B_{max.}$ *on 12 different Waves.*

Wave No.	Amplitude Factor.	Mean Ordinate Factor.	Armature.	Lohys.	Stalloy.
1	1·570	0.872	1·220	1·205	0·685
4	1·535	0·878	1·253	1·217	0·693
10	1·415	0·888	1 ·23	1·236	0·707
9	1·415	0·888	1·253	1·236	0·707
7	1·420	0·888	1·255	1·236	0·708
5	1·385	0·894	1·268	1·247	0·715
3	1·445	0·895	1·269	1·247	0·716
6	1·435	0·896	1·271	1·250	0·718
12	1·415	0·899	1·277	1·257	0·724
11	1·420	0·908	1·298	1·275	0·735
2	1·295	0·914	1·310	1·285	0·743

Table H.

Test at 10,000 Nominal $B_{max.}$ *on Waves 1 and 2 at various Periodicities.*

Periodicity.	Joules per Lb. per Cycle.					
	Armature.		Lohys.		Stalloy.	
	No. 1.	No. 2.	No. 1.	No. 2.	No. 1.	No. 2.
0	0·01180	0·01990	0·0160	0·0176	0·01130	0·01245
25	0·02125	0·02305	0·0200	0·0216	0·01250	0·01365
37½	0·02280	0·02460	0·0221	0·0237	0·01310	0·01425
5	0·02440	0·02620	0·0241	0·0257	0·01370	0·01485
62½	0·02600	0·02780	0·0260	0·0276	0·01430	0·01545
75	0·02755	0·02935	0·0281	0·0297	0·01485	0·01600
10	0·03070	0·03250	0·0321	0·0337	0·01605	0·01720

Stalloy is more uniform—the exponent only goes up to about 1·8 at the higher inductions.

Table F refers to the same test and shows the percentage difference in the total losses on the two waves. The percentage difference for Armature is about constant up to 10,000 $B_{max.}$, but then increases

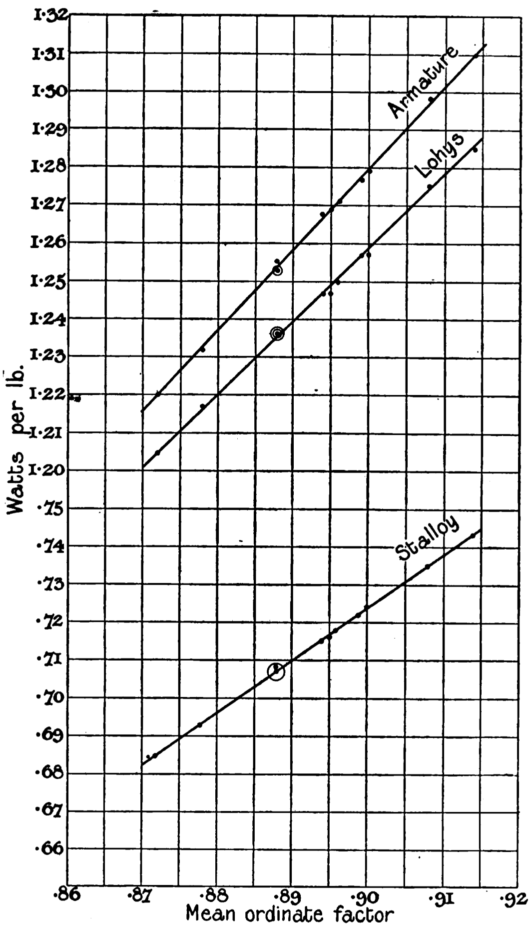


FIG. 8.

greatly. Lohys shows a minimum percentage difference at about 5,000 $B_{max.}$ with an increase at 2,500, and a much larger increase at 15,000. Stalloy behaves much as Armature, the difference being fairly constant to 10,000 and then increasing considerably.

The difference in the mean ordinate factors of the two waves is 4·8 per cent. and the difference in the true $B_{max's.}$ must also be 4·8 per

cent. Yet the difference in the total loss sometimes amounts to over 10 per cent. in spite of the fact that probably only the hysteresis portion of the loss is affected by wave-form.

Table G sets forth the loss in watts per pound at 10,000 nominal $B_{max.}$ and 50 periods on waves Nos. 1 to 12. It will be noticed that

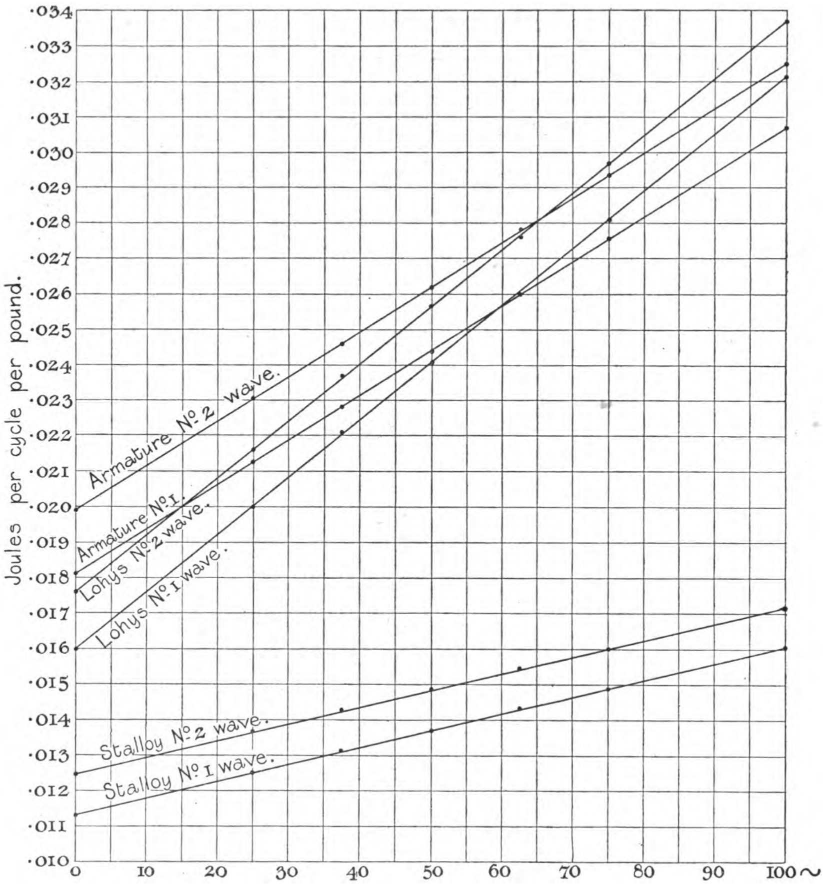


FIG. 9.

the total loss increases in the same order as the mean ordinate factor, the amplitude factors having very little to do with it.

The figures of this table are plotted out in curves in Fig. 8. The ordinates are watts per pound and the abscissæ mean ordinate factors. The dots, it will be observed, all fall within 0·2 per cent. of the curves.

In Table H will be found the total losses in joules per pound per cycle on waves 1 or 2 at 10,000 nominal $B_{max.}$ and at various periodicities. The figures from this table are given in the form of curves in Fig. 9.

These curves are simple, parallel straight lines, showing that the total losses can be divided into two parts: the one, generally called hysteresis, is independent of periodicity but dependent upon wave-form; the second, generally known as eddies, is proportional to periodicity and independent of wave-form.

The tests were made at periodicities from 100 down to 25; the curves have been extended to zero by exterpolation. At zero periodicity eddies must be zero, so the hysteresis and eddy losses are thus readily separated.

Tests recently made by Messrs. Lloyd and Fisher at the National Bureau or Standards (Bulletin of the Bureau of Standards, vol. 5, No. 4) show that the curves are no longer straight at higher periodicities, the curves beginning to bend downwards a little from 90 periods and upwards. The author has found no evidence of this bend in his

TABLE I.

Test at 10,000 *Nominal* $B_{max.}$ *on Waves* 1 *and* 2 *at Various Periodicities.*

Periodicity.	Percentage of Eddies in Total Loss.					
	Armature.		Lohys.		Stalloy.	
	No. 1.	No. 2.	No. 1.	No. 2.	No. 1.	No. 2.
25	14·8	13·6	25·2	18·6	9·6	8·8
50	25·8	24·0	33·5	31·4	17·5	16·2
75	33·2	31·2	43·1	40·8	23·9	22·2
100	41·0	38·8	50·3	47·6	29·6	27·6

tests, but as in the case cited the droop at 100 periods was less than 1 per cent. and thicker specimens were employed, it is not very surprising that the author's results were not quite confirmed at 100 periods.

It will be observed that Lohys has a smaller hysteresis loss than Armature, but that the eddies are greater. At below 60 periods the total loss is less in Lohys, above 60 periods Armature is the better of the two.

Stalloy claims to have an exceedingly small eddy loss. This is confirmed; but it should also be noted that a great deal of the improvement is due to a reduction of the hysteresis loss also.

Table I. shows the percentage of eddies in the three samples. This varies from 9 per cent. for Stalloy at 25 periods up to 50 per cent. for Lohys at 100 periods. The percentage of eddies is zero at zero frequency, and in each case rises steadily as the periodicity increases.

Still referring to the same test, Table J shows the percentage difference in total loss on the two waves. All three samples are affected by about 10 per cent. at zero frequency. At higher periodicities the percentage difference decreases as the percentage of eddies increase. At 100 periods Armature is affected 5·9 per cent., Lohys 5 per cent., and Stalloy 7·2 per cent.

It should be noted that a difference of 4·8 per cent. in the mean ordinate factor of the wave, corresponding to a difference of the same percentage in the true $B_{max.}$ alters the hysteresis loss by no less than 10 per cent. for all three samples.

It is evident from these tests that differences of the order of 7 per cent. are likely to be found by different authorities in the total losses if due attention is not paid to wave-form. Such differences are

TABLE J.

Transformer Iron Tests at 10,000 Nominal $B_{max.}$ on Waves 1 and 2, and Various Periodicities.

Periodicity.	Difference per Cent.		
	Armature.	Lohys.	Stalloy.
0	10·0	10·0	10·2
25	8·5	8·0	9·2
50	7·4	6·7	8·4
75	6·5	5·7	7·7
100	5·9	5·0	7·2

sufficiently great to lead to disputes and to cause general inconvenience, especially when the iron is paid for by results.

EFFECT OF WAVE-FORM ON DIELECTRIC STRENGTH.

It is sometimes assumed that the breakdown of an insulating material is directly related to the maximum value of the E.M.F. wave. On consideration, however, it is evident that this may not always be the case. If the insulation resistance of the material is low, there may be a sufficient leakage current passing to heat up the material seriously. Such leakage would depend more upon the R.M.S. than the maximum value of the E.M.F., and breakdown in extreme cases might take place on the same R.M.S. voltage whatever the wave-form.

The presence of dielectric hysteresis and capacity also complicates matters, so that it is difficult to forecast with certainty what will be the effect of wave-form in any particular case.

The carrying out of tests to ascertain the effect of wave-form on dielectric strength presents great difficulties. The results obtained are generally very erratic, apparently due to want of homogeneousness in the material. The author has therefore confined himself to carrying out tests on air and oil. The results of these tests, though far from exact, confirm what has already been said, that the breakdown of an insulating material is not always to be referred to the maximum value of the wave.

Dielectric Strength of Air.

Tests were made on waves 1 to 7, using spheres 2·22 and 4·5 cms. diameter and 1 cm. apart. The wave-forms were preserved by using an auto-transformer, the field being only adjusted for the last 5 per cent. of the raising of the pressure. The voltage was raised in steps of ½ per cent. at 10-second intervals.

The results of the tests are given in Table K, the R.M.S. and maximum voltage of each wave being given.

It is shown that for air the breakdown depends entirely upon the maximum of the wave, the greatest divergence from the mean of all 7 maximums being only 1⅓ per cent. for wave No. 5 and with the smaller spheres.

Correcting by Dr. Russell's tables,* the dielectric strength of air works out to 39 kilovolts for the smaller spheres and 35 kilovolts for the larger ones. This difference roughly confirms the results found by Mr. E. A. Watson,† who suggested as a possible explanation of the variation that air had a higher resistance in the neighbourhood of a conductor than at some distance from it.

Effect of Wave-form on the Dielectric Strength of Oil.

Three samples of oil were tested on waves 1 and 2 with spheres 4·5 cms. diameter fully immersed in the oil. The voltage was generated by one transformer, a second potential transformer being used to step down the voltage to an electrostatic voltmeter. The voltage had to be regulated to a large extent on the field, as the time taken to change over transformer connections would have seriously interfered with the procedure necessary to be observed in making such tests. The wave-forms were not, therefore, quite preserved to standard and the amplitude factor of No. 1 may have sometimes been as much as 2 per cent. above standard and that of No. 2 2 per cent. below standard.

The oils were first dried by heating up to 230° F. for half an hour and were then left overnight to cool. Even after drying, the results obtained were so erratic that it was necessary to make a large number of tests to obtain an average for comparison.

The method employed was as follows: The first application of the voltage was at about half the average breakdown voltage. The

* *Journal of the Institution of Electrical Engineers*, vol. 40, pp. 9–10, 1908.

† Ibid., vol. 43, p. 113, 1909.

pressure was raised in steps of 2 per cent. at intervals of 10 seconds. After each breakdown the oil was stirred by rocking the electrodes backwards and forwards through the oil without actually removing them above the surface. A test was first made on No. 1 wave, then two on No. 2, then two on No. 1 again, and so on to the finish.

Each breakdown was a regular short circuit and blew a 2-ampere fuse in the primary circuit of the transformer. There was none of the intermittent flicking that is so troublesome in oil not dried.

TABLE K.

The Relation between Wave-form and the Dielectric Strength of Air. Tests between Spheres, 1 cm. apart.

Wave No.	Ampere Factor.	Spheres, 2·22 cms. Diameter.		Spheres, 4·50 cms. Diameter	
		R.M.S. Kilovolts.	Maximum Kilovolts.	R.M.S. Kilovolts.	Maximum Kilovolts.
1	1·570	18·6	29·200	19·2	30·200
2	1·295	22·7	29·400	23·5	30·300
3	1·445	20·5	29·600	20·9	30·200
4	1·535	19·1	29·400	19·7	30·300
5	1·385	21·6	30·000	22·0	30·500
6	1·435	20·5	29·600	20·9	30·200
7	1·420	20·8	29·6c0	21·5	30·600
Average		—	29·500	—	30·300
X/A		—	0·900	—	0·445
F		—	1·321	—	1·550
Dielectric strength		—	39·000	—	35·000

Three samples of oil were tested, known as Wilcox light dynamo oil, Duckham transformer oil, and resin oil. The two former were found to be pure mineral oils; the last is a vegetable oil. As a guide to quality of the oils, their viscosities at 70° F. were tested and were found to be 67, 40, and 81 respectively. As far as the tests go it would appear that high viscosity is accompanied by high dielectric strength, but this might not be borne out if more samples were tested.

Table L shows the breakdown voltages obtained. They are so very erratic that the only thing to do is to take an average of all on

TABLE L.

Effect of Waves Nos. 1 *and* 2 *on Dielectric Strength of Three Samples of Oil. Ratio of Amplitude Factors,* 1·21. *Spheres,* 4·50 *cms. Diameter.*

WILCOX LIGHT DYNAMO OIL. Viscosity, 67 at 70° F. Spheres, 1·5 mm. apart. R.M.S. Kilovolts.		DUCKHAM TRANSFORMER OIL. Viscosity, 40 at 70° F. Spheres, 2 mm. apart. R.M.S. Kilovolts.		RESIN OIL. Viscosity, 81 at 70° F. Spheres, 1 mm. apart. R.M.S. Kilovolts.	
Wave No. 1.	Wave No. 2.	Wave No. 1.	Wave No. 2.	Wave No. 1.	Wave No. 2.
9·5	10·5	12·3	16·8	13·9	1·76
20·0	19·9	12·5	16·1	12·4	11·6
16·4	20·5	14·2	17·0	15·0	18·1
16·9	17·7	14·6	16·7	13·7	14·3
15·9	22·8	13·9	14·8	13·5	13·6
16·5	16·3	14·6	16·4	15·3	15·6
15·0	19·4	14·0	14·4	13·7	12·5
14·5	18·6	15·2	14·2	13·7	12·6
14·1	18·7	13·2	13·7	13·1	12·1
14·5	21·2	13·5	16·1	13·1	12·7
13·2	19·8	12·3	17·3	13·0	12·5
18·0	22·0	15·6	16·4	11·1	12·1
14·2	21·2	17·5	14·2	10·2	10·0
—	—	15·9	18·5	8·8	8·1
—	—	18·7	17·0	—	—
Average 15·3	19·1	14·5	16·0	12·9	13·1
Ratio ... 1·245		1·13		0·985	

each wave. The ratio of the two amplitude factors of the waves was 1·21, or perhaps a little more, due to the alternator field not always being at full strength. The average of the R.M.S. breakdown voltages is: For the Wilcox oil, 1·245; for the Duckham oil, 1·13; and for the resin oil, 0·985.

These ratios cannot be taken as very exact owing to the variation of individual results, but they are sufficiently exact to show that the dielectric strength of oil should not be stated in terms of the maximum voltage of the wave in every case.

The Wilcox oil appears to depend upon the maximum value of the wave for its breakdown, the resin oil upon the R.M.S. value, and the Duckham oil upon something half-way between the two.

It was noticed that before the oils broke down they generally began to sing. This singing appeared to be more pronounced in the case of the resin oil than with the others. It was thought that perhaps leakage had some influence upon these results.

In order to test this point the author measured the insulation resistance of the oils. The tests were made in the tank with the spheres separated 1 mm. in each case. The testing pressure was 500 volts.

The resin oil came out at 47,000 megohms, the Duckham at 34,000 megohms, and the Wilcox oil at 8,400 megohms, which is in exactly the reverse order to that required to account for their peculiar behaviour when the wave-form is varied.

It is, however, improbable that the insulation resistances are maintained when the samples are subjected to a voltage approaching that at which they break down.

An attempt was made to measure the watts consumed by these three samples up to the point of breakdown. The most sensitive wattmeter available for the test was a dynamometer instrument with a range of 10 watts, together with a potential transformer with a 100 to 1 ratio extending the range to 1,000 watts.

No deflection of this instrument was obtained with any of the samples right up to the point of breakdown, when a momentary kick was observed just as the fuse blew. Had any of the oils taken as much as a quarter of a watt a deflection would have been observed, though it could not have been read with accuracy.

In view of the small power consumed it hardly looks as if the breakdown was in any of the three oils or on either wave accelerated by local heating.

Effect of Wave-form on Induction Meters.

House service meters of the induction type have long been suspected of being affected by wave-form. When one inquires of the makers, however, the usual answer one gets is that no doubt other meters are badly affected by wave-form, but their own hardly at all.

To test every make of meter on the market at all sorts of loads and periodicities would have been too big a task for the author to undertake. He has accordingly had to content himself with testing 6 meters on 6 loads and 2 waves. This alone meant over a week's work. The meters were all rated at 10 amperes, 110 volts, and 50 periods.

The differences to be discovered being small, special precautions had to be undertaken to detect them properly. The loads were chosen

to suit the wattmeter, so that a deflection at the top of the scale could always be obtained. The alternator was run on load for 1 hour before starting in order to secure that the frequency should not vary excessively during the tests. At each load 6 tests were made on each wave, the two sets of tests being sandwiched between each other and the wattmeter being always brought up to the same reading for each set of tests.

The wattmeter could be read to an accuracy of 1 part in 2,000. The revolutions were counted through about 100 seconds on a stop-watch beating $\frac{1}{10}$th second. By taking the average of 6 tests on each wave the author believes that he has obtained the differences to 1 part in 1,000, or 0·1 per cent.

Tests were made on noninductive loads and also at 375 watts and 0·5 power factor. The latter tests were made on a choking coil with air core. The two E.M.F. waves not being sines, it follows that on inductive load the current waves differed considerably from the E.M.F. waves. No record was made of these current waves, but they ought to be calculable, the power factor being known.

TABLE M.

Effect of Wave-form on Meters. All Meters Rated at 110 *Volts,* 10 *Amperes, and* 50 *Periods. Percentage Effect on Changing Over from No.* 1 *to No.* 2 *Waves.*

Watts.	Power Factor.	B.T.H.	Aron.	Westinghouse.	Ferranti.	Siemens.	Alva.
1,000	1·0	0·2−	0·5+	0·1+	0·7−	0·5+	0·3−
750	1·0	0·3−	0·5+	0·1+	0·6−	0·4+	nil
500	1·0	0·3−	0·6+	0·1+	0·5−	0·4+	0·3+
200	1·0	0·5−	0·4+	0·3+	0·4−	0·3+	0·6+
100	1·0	0·5−	0·5+	0·4+	0·2−	0·3+	0·8+
375	0·5	0·1+	0·2+	0·7+	0·4+	0·3−	1·0−

The results obtained are embodied in Table M. In addition, each meter was also tested on a non-inductive load of 500 watts and a sine wave. These results are omitted from the table, as these tests were not made with the same degree of accuracy, tests on a sine wave being made only at the start and finish of the other tests when the conditions may have been slightly different. It is sufficient to say, however, that on a sine wave each meter ran at a speed about midway between the speeds on waves Nos. 1 and 2. The object of making the tests on the sine wave was merely to ascertain that there was not some effect

depending upon the harmonics, but quite apart from amplitude or mean ordinate factor, which would make the meters run either much faster or much slower on a sine than on either a flat or peaked wave.

It is to be observed that 2 meters run faster on the flat wave throughout, 2 slower on non-inductive and faster on inductive load, 1 exactly opposite to this, and the last runs on No. 2 wave slower on full load but faster on the lower loads, and slower again on an inductive load.

The author cannot give any explanation of why the different meters should behave so differently to each other on changing the wave-form, but probably it has something to do with the iron losses and magnetising currents of the shunt coils. If the differences were larger the matter could be further investigated by testing on other waves, but with such small differences occurring such an investigation would be very difficult and hardly worth while.

The effect of wave-form is so small with these meters as to be of little or no consequence.

The following is a brief description of the main features of the meters:—

B.T.H.

The cores are entirely laminated. The main current divides between two coils in parallel. One of these has a maximum of self-induction and the other has a resistance in series with it. The combined fields lead with respect to the outside current and true quadrature between shunt and series fields is thus obtained. Friction is compensated for by a magnetic starting horn.

Aron.

The cores are entirely laminated. Quadrature is secured by putting a short-circuit secondary winding on shunt core. Friction is compensated for by means of a strip of iron on poles.

Westinghouse.

The cores are entirely laminated. Quadrature is secured partly by providing a leakage path for the shunt field and partly by a short-circuit secondary winding on shunt poles. Friction is compensated for by short-circuited winding on leakage field.

Ferranti.

The cores are entirely solid. Quadrature is secured by the use of solid iron and is adjusted by altering the position of the shunt coil on its core. Leakage field also helps the production of quadrature. Friction is compensated for by turning the series cores a little out of symmetry with respect to the shunt poles.

Siemens.

Cores are laminated. Quadrature is adjusted by short-circuited secondary winding on shunt core.

Alva.

Cores are partly laminated and partly solid. Quadrature is partly secured by the use of solid iron and partly by providing a leakage path for the shunt field. Friction is compensated by an eddy disc on poles.

A consideration of the special features of the meters as outlined above does not appear to the author to throw any light upon the individual behaviour of the meters on a changing wave-form.

ORIGINAL COMMUNICATION.

EXPERIMENTAL DETERMINATION OF THE MOMENT OF INERTIA OF A CONTINUOUS-CURRENT ARMATURE.

By Dr. GISBERT KAPP.

(*Received November* 24, 1909.)

For the experimental analysis of frictional and other losses by the so-called "running-out test" the knowledge of the moment of inertia of the armature is required. There are two well-known methods for determining this: one by the addition of a flywheel of known moment of inertia, the other by the application of a brake of constant and known torque. In the first method the running-out time is lengthened, in the second it is shortened. In so far the first method is preferable as being less liable to errors of observation which are likely to arise when readings of time and speed have to be taken very quickly. On the other hand, the preparation of a special flywheel is costly and its weight may alter the frictional resistance in the bearings, so that to eliminate this new source of error one is obliged to prepare two pieces, one the flywheel proper of such shape as to give a maximum moment of inertia, and another of equal weight, but so shaped that its moment of inertia shall be as small as possible. Apart from the expense there is the limitation that the method is only applicable if there is room on the shaft for a flywheel. This limitation also applies to the brake method, though the expense of rigging up such a brake is much smaller than that for a flywheel and its counterpart. Where there is no room on the shaft either for a flywheel or a brake pulley, neither method is possible, and then the running-out test cannot be used for the analysis of losses.

In the following I shall describe a method for finding the moment of inertia by making a running-out test without interfering in any way with the machine mechanically. The method has also the merit of requiring no special apparatus and being therefore inexpensive. The leading feature of this method is to substitute electrical for mechanical action, but before entering into details it will be useful to say a few words about the two orthodox methods.

Brake Method.—Round the shaft itself, or preferably round a small

pulley on the shaft is laid a composite band consisting of a strip of leather to which is joined a very thin strip of metal. Both ends are weighted, the larger weight being put on to the end of the metal strip, and the band is laid over in such a way that the friction between band and pulley tends to lift the larger weight. The higher it is lifted the smaller becomes the arc spanned by the leather and the larger that spanned by the metal strip. Since the friction of the leather is the greater, the tendency to lift the large weight diminishes as the weight rises, and thus the system has a condition of equilibrium and exerts a constant retarding torque on the shaft. This torque is the product of the radius of the pulley and the difference between the two weights. To make the test accurate the brake torque should be of about the same order of magnitude as the retarding torque of journal and brush friction, and thus the running-out time, which for convenience and accuracy of observation is none too long to begin with, is by the addition of the brake considerably shortened. To make a reliable test by this method requires, therefore, considerable skill.

Flywheel Method.—Since by this the running-out time is lengthened the attainable accuracy is greater. The flywheel is generally prepared in the form of a plain solid disc, preferably of boiler plate, because the moment of inertia of such a body can be accurately calculated from its diameter and weight. It is equal to that of half the mass concentrated in a point on the circumference. Let W be half the weight of the disc in kilogrammes and r the radius in metres, then the moment of inertia is—

$$I = \frac{W}{9 \cdot 81} r^2 \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

and the power in watts corresponding to a speed gradient of $\frac{d u}{d t}$ is—

$$P = 9 \cdot 81 \times 4 \pi^2 u I \frac{d u}{d t} \qquad P = 388 u I \frac{d u}{d t} \quad . \; . \; . \; . \quad (2)$$

where u is the speed in revolutions per second and t the time in seconds. To make the test in the usual way we have to prepare the disc flywheel of large diameter, and its counterpart which may conveniently be a long cast-iron cylinder of equal weight. Its diameter is very much smaller, and the two moments of inertia will be in the proportion of the squares of the diameters.

The disc shape has only been adopted because the moment of inertia can easily and accurately be calculated, but if we had another means of finding it, the shape of the flywheel would be immaterial. Any existing flywheel or heavy pulley could be used, provided it will stand the centrifugal stress; and we are able by a simple preliminary experiment to determine its moment of inertia. This may be done by suspending the wheel bifilarly or trifilarly with its axis vertical, and observing the time of swing round the axis. Let l be the length of the suspension (thin steel wire cables may conveniently be used) and

a the distance of each of the suspending wires from the axis of the wheel, then the time of a complete period is

$$T = 2\pi \sqrt{\frac{I\,l}{W\,a^2}},$$

l and a being given in metres. From this expression we deduce—

$$I = \frac{91\,a^2\,W}{n^2\,l}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where n is the number of complete periods gone through by the swinging system in one minute.

The expense of preparing a special flywheel may thus be saved by using any kind of wheel and swinging it on a bifilar or trifilar suspension. The counterpart of equal weight must, however, be specially prepared, and its moment of inertia determined either also by bifilar swinging, or if it is a plain cylinder, by calculation. In high-speed journals where the specific pressure is small, the frictional resistance is almost independent of small variations of specific pressure, so that the expense of preparing a counterpart need not be incurred. To make the treatment general, I assume, however, that a counterpart is used.

Let I be the moment of inertia of the armature alone, I_1 that of the flywheel, and I_2 that of the counterpart, then by making a running-

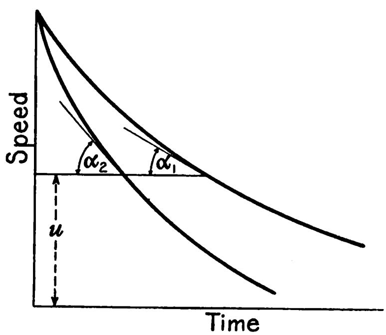


FIG. 1.

out test first with the flywheel and then with the counterpart we obtain the two time-speed curves as shown in Fig. 1. For any particular speed u we have two equations, namely—

$$2\,\pi\,u\,61{\cdot}6\,(I + I_1)\,tg\,\alpha_1 = F\,u + L \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$2\,\pi\,u\,61{\cdot}6\,(I + I_2)\,tg\,\alpha_2 = F\,u + L \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where $F\,u$ denotes the frictional loss in watts and L all the other losses (hysteresis, eddy currents, and windage) at that particular speed and excitation. If the machine is non-excited during the running-out test then L is merely the windage loss.

The moment of inertia of the armature is—

$$I = \frac{I_1 \, tg\, a_1 - I_2 \, tg\, a_2}{tg\, a_2 - tg\, a_1} \quad \ldots \ldots \ldots \quad (6)$$

Since I is now known we can, from (4) or (5), determine F u + L, and if the curves in Fig. 1 refer to the non-excited machine, also F u alone, since for very low speeds the windage loss is negligible. Thus the value of F may be determined, but only for this particular low speed. Dettmar has found experimentally * that F may be considered as approximately proportional to the square root of the speed. The friction and windage loss may then be expressed by $F u^{1 \cdot 5} + V u^v$, where $L = V u^v$ represents windage loss, which is proportional to u^v.

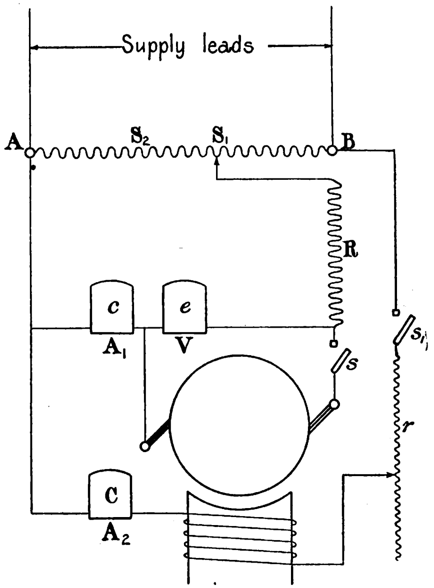


FIG. 2.

By analysing the running-down curves of various machines I have found the exponent v to lie between 2·2 and 2·5. The magnetic losses can be determined in the well-known way by making other running-out tests with the machine excited, though for this purpose the electrical methods developed by Mr. Housman, Mr. Dettmar, and the author for the separation of losses are preferable.

I shall now describe the new electrical method, not for the separation of losses, but merely for the determination of the moment of inertia of the armature. The machine is run light as a motor, the con-

* Arnold, *Die Gleichström*, Maschine i., p. 496.

nections to the constant voltage supply mains being made as shown in Fig. 2. A B is a main current regulator, and R a resistance, the value of which need not be accurately known. The field is magnetised from the mains and the excitation is regulated by a rheostat *r*. The amperemeter A_2 measures the exciting current C, which should be kept as low as possible for full speed and a reasonably small armature current *c* which latter is measured on the amperemeter A_1. The voltmeter V indicates the brush voltage *e*, and this for a low armature current may be taken as equal to the induced voltage, so that the product $e \times c$ represents at any moment the power given out or taken in by the armature. If the switch *s* is left closed and the slider on the main current regulator be run back to point A, then the inertia of the armature will be the source of power not only to cover the normal losses, but also the ohmic loss in R. It will therefore very quickly come to rest, and a test made on these lines would be open to the same objections as mentioned above in connection with the brake test, and in fact even more so, because the

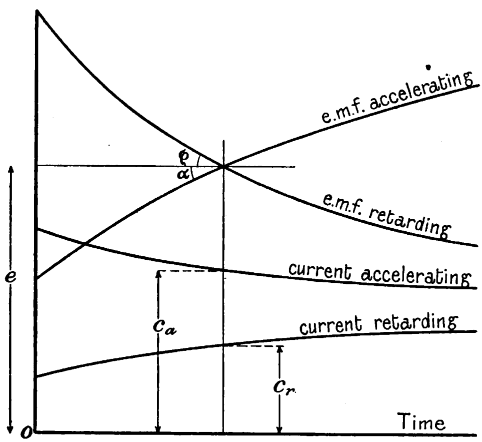


FIG. 3.

speed-time line would be still steeper. But if we set the slider on the main current regulator some distance from A, so that the armature receives power electrically, then we can prolong the time of running out to any desired degree and thus obtain any desired slope on the retardation curve. This permits of longer intervals being used between the readings and a correspondingly greater degree of accuracy. The excitation is kept constant throughout the test so that apart from a slight correction for armature and brush contact resistance (which can easily be made if desired) the brush voltage is proportional to the speed, or—

$$e = u\beta$$

where β is a coefficient depending on the excitation and is determined once for all by taking a speed and E.M.F. reading when the machine is running steadily.

Let L now represent all the losses at a particular speed u, then the power equation for that speed is—

$$e c = \mathrm{L} + 2 \pi u \mathrm{I} \, 2 \pi \frac{d u}{d t} 9{\cdot}81,$$

$$e c = \mathrm{L} + 4 \pi^2 9{\cdot}81 \; u \; \mathrm{I} \frac{d u}{d t},$$

$$e c = \mathrm{L} + \frac{388}{\beta^2} e \mathrm{I} \frac{d e}{d t} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (7)$$

By manipulating the main current regulator, or simply a rheostat put in series with the armature which can be lengthened and shortened so as to slow down or speed up the machine, we can make two runs at the same excitation—one to get retardation, the other to get acceleration of the armature. By plotting the observed voltage and current against time we get the curve shown in Fig. 3. Let e be the E.M.F. at the crossing-point and let the corresponding values of the currents be c_r for the retardation curve and c_a for the acceleration curve. The tangents to the curves for e at the crossing-point give the volt gradients, that for the retardation curve being negative. We thus get the following equations :—

$$e c_r = \mathrm{L} - \frac{388}{\beta^2} e \, \mathrm{I} \, tg \, \rho \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (8)$$

$$e c_a = \mathrm{L} + \frac{388}{\beta^2} e \, \mathrm{I} \, tg \, a \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (9)$$

and deducting (8) from (9) we have—

$$c_a - c_r = \frac{388}{\beta^2} (tg \, a + tg \, \rho) \, \mathrm{I}$$

$$\mathrm{I} = \frac{\beta^2}{388} \frac{c_a - c_r}{tg \, a + tg \, \rho} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (10)$$

The special case that $\rho = 0$ and the retardation curve is a straight line means that the machine is running steadily taking c_0 ampere to drive itself. In this case we have—

$$\mathrm{I} = \frac{\beta^2}{388} \frac{c_a - c_0}{tg \, a} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (11)$$

Thus the test is reduced to one steady run at e volts, by which β and c_0 is found, and an acceleration run during which observations of voltage and current as a function of the time must be taken. The observations need, however, only be taken over a limited range from a little below e to a little above e; only sufficient to draw the tangent to the E.M.F. time curve accurately.

I have tried this method on machines up to 30 k.w. and found it reliable; that is, the values of I obtained by it were in accord with the values obtained by the brake method. The electrical method would seem to be specially advantageous for large flywheel sets and large machines generally, where an extra flywheel or a brake would be impracticable.

ORIGINAL COMMUNICATION.

THE THEORY OF THE DYNAMOMETER WATTMETER.

By CHARLES V. DRYSDALE, D.Sc.

(*Received September* 8, 1909.)

Although much has been written on the dynamometer wattmeter, no very complete theory of its errors has been given, notably as regards the effects of eddy currents and wave-form, and the following is an attempt at such a theory. Of the various causes of error in such instruments, that due to reactance in the shunt circuit is the best known and most important, and I have shown* that the correction for this reactance is best expressed in the following form :—

$$w = w' (1 + T^2 p^2) - T p W \sin \phi,$$

where w is the true power in watts, w' the power indicated by the wattmeter, W the apparent power in watts, T the time constant of the shunt circuit, ϕ the angle of lag, and $p = 2\pi \times$ frequency of the current for sine waves. In all good instruments the term $T^2 p^2$ is negligible in comparison with unity, and we may write $w = w' - T p W \sin \phi$ as the standard or characteristic formula for the dynamometer wattmeter.

The other causes of error are, as is well known : (*a*) mutual induction between the coils, (*b*) eddy currents induced by the main or shunt coil fields in masses of metal or in the material of the coils, and (*c*) electrostatic attraction between the coils. Of these the last can always be eliminated by connecting the instrument so that there is no appreciable difference of potential between the coils.

The resultant mean torque in a dynamometer wattmeter is proportional to the mean product of the current in the shunt coil, and the resultant stationary flux in which it moves. All the phenomena which take place in the instrument may be classified as affecting either the shunt current or the stationary field. The above diagram, Fig. 1, symbolically represents the whole of the electromagnetic connections of a dynamometer wattmeter. Here the main current C traverses a coil having a coefficient of mutual induction M with the shunt coil, and

* *Electrician*, vol. 46, p. 774, 1901, and *L'Industrie Électrique*, p. 125, 25 March, 1901.

of M_a with the metal parts of the instrument. The shunt circuit is made up of the resistance r_1, shunted by the capacity K, and of the coil having inductance L, resistance r_2, and reactance x_2, and a coefficient of mutual induction M_b with the metal parts. These metal parts are represented as a short-circuited coil of resistance r_3 and reactance x_3. Lastly, the resultant external circuit is represented by the coil of resistance R and reactance X.

Shunt Circuit.—The potential difference at the terminals of the shunt is made up of four components:—

(*a*) Resistance voltage, $v_1 = rc$.
(*b*) Reactance voltage, $v_2 = L'\dot{c} = -jx'c$ where x' is the resultant reactance of the shunt.
(*c*) E.M.F. of mutual induction $v_3 = M\dot{C} = -jMpC$.
(*d*) E.M.F. induced by eddies.

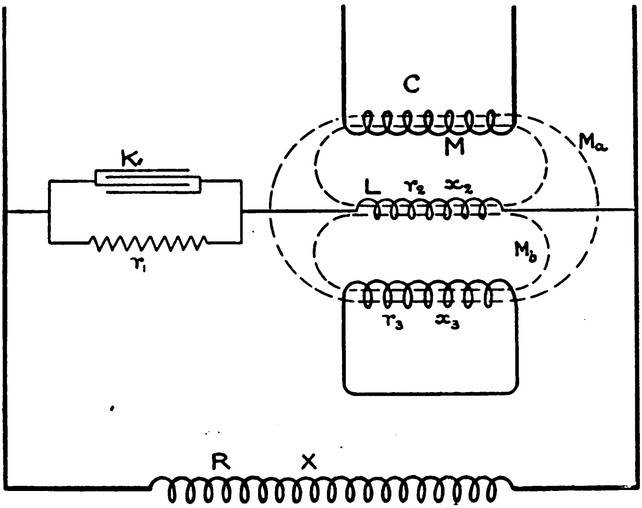


FIG. 1.

Resultant Field.—This is made up of four components:—

1. Due to main current.
2. Due to shunt current.
3. Due to eddy currents induced by main field.
4. Due to eddy currents induced by shunt field.

It is also affected by hysteresis in the case of iron-cored instruments.
Of the various component fields above (2) may be neglected, as it must always move with the shunt coil.

Equivalent Inductance of Shunt Circuit.—The equivalent impedance of the shunted capacity—

$$I_1 = \frac{1}{\dfrac{1}{r_1} - j\,K\,p} = \frac{r_1\,(1 + j\,K\,r_1\,p)}{1 + K^2\,r_1^2\,p^2}.$$

When there is no metal in the field of the moving coil its impedance—

$$I_2 = r_2 - j\,L\,p.$$

Hence total impedance—

$$I = I_1 + I_2 = \frac{r_1 + r_2 + K^2\,r_1^2\,r_2\,p^2 - j\,(L - K\,r_1^2 + L\,K^2\,r_1^2\,p^2)\,p}{1 + K^2\,r_1^2\,p^2},$$

or—

$$I = \frac{r_1 + r_2 - j\,(L - K\,r_1^2)\,p}{1 + K^2\,r_1^2\,p^2} + \frac{r_2 - j\,L\,p}{1 + K_2\,r_1^2\,p^2}\,K^2\,r_1^2\,p^2,$$

and—

$$\tan\alpha = \frac{L - K\,r_1^2 + L\,K^2\,r_1^2\,p^2}{r_1 + r_2 + K^2\,r_1\,r_2^2\,p^2}\,p \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

When $K\,r_1\,p$ is small in comparison with unity—

$$I = r_1 + r_2 - j\,(L - K\,r_1^2)\,p = r - j\,(L - K\,r_1^2)\,p,$$

and—

$$\tan\alpha = \frac{L - K\,r_1^2}{r_1 + r_2}\,p = \frac{L - K\,r_1^2}{r}\,p,$$

where r is the total resistance of the shunt circuit.

Effect of Metal in Field of Shunt Coil on its Impedance.

If c is the current in the shunt coil and M_b the mutual inductance with any metal parts of the instrument, an E.M.F. e_3 is induced in these parts such that—

$$e_3 = -\,M_b\,\dot{c}.$$

This sets up a current—

$$c_3 = \frac{e_3}{I_3} = -\,\frac{M_b}{I_3}\,\dot{c}.$$

The current induces an E.M.F. in the shunt coil—

$$e_2 = -\,M_b\,\dot{c}_3,$$

or—

$$e_2 = \frac{M_b^2}{I_3}\,\ddot{c}.$$

For a simple harmonic current—

$$\ddot{c} = -\,p^2\,c \quad \text{and} \quad I_3 = r_3 - j\,x_3,$$

hence—

$$e_2 = -\,\frac{M_b^2\,p^2}{r_3 - j\,x_3}\;c = -\,\frac{M_b^2\,p^2}{I_3^2}\,(r_3 + \;\; x_3)\,c.$$

The effect of the metal is therefore to increase the equivalent impedance of the circuit by the amount—

$$\frac{M_b^2 p^2}{I_3^2}(r_3 + j\,x_3);$$

or to increase the equivalent resistance by—

$$\frac{M_b^2\, r_3\, p^2}{I_3^2},$$

and decrease the equivalent inductance by—

$$\frac{M_b^2\, L_3\, p^3}{I_3^2}.$$

For a shunt circuit containing both inductance and capacity, and having metal included in its field, we therefore see that the equivalent shunt resistance—

$$r' = \frac{r_1 + r_2 + K^2\, r_1^2\, r_2\, p^2}{1 + K^2\, r_1^2\, p^2} + \frac{M_b^2\, r_3\, p^2}{I_3^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

and the equivalent shunt reactance—

$$x' = \left(\frac{L - K\, r_1^2 + L\, K^2\, r_1^2\, p^2}{1 + K^2\, r_1^2\, p^2} - \frac{M_b^2\, L_3\, p^2}{I_3^2}\right)p \quad . \quad . \quad . \quad . \quad (3)$$

while the equivalent shunt impedance—

$$I' = \sqrt{r'^2 + x'^2}.$$

Current Induced in Shunt by Main Coil.—The E.M.F. induced in the shunt coil by the current in the main coil is $v_3 = -M\dot{C} = j\,M\,p\,C$. The shunt current thus produced will then be—

$$\frac{j\,M\,p\,C}{r' + R - j\,(x' + X)} = \left\{-(x' + X) + j\,(r' + R)\right\}\frac{M\,p\,C}{I''^2} \quad . \quad . \quad (4)$$

where I″ is the total impedance of the shunt and the external circuit combined in series.

If the main current is expressed in the form C $(\cos\phi + j\sin\phi)$, the shunt current produced by it will then be—

$$= \Big[-\left\{(x' + X)\cos\phi + (r' + R)\sin\phi\right\} + j\left\{(r' + R)\cos\phi - (x' + X)\sin\phi\right\}\Big]\frac{M\,p\,C}{I''^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Current Induced in Shunt by Stationary Field.—Instead of considering the current induced in the shunt by the main current alone, we may conveniently find the current induced by the portion of the total resultant stationary field cutting the shunt coil. If this field has an

effective strength N, and is represented by $\dot{N}$ (cos $\theta + j$ sin θ), we have for the E.M.F. induced in the shunt $-\dot{N}\,t = j\,\dot{N}\,tp$, where t is the number of turns in the shunt coil.

The shunt current is therefore—

$$\Big[-\big\{(x' + X)\cos\theta + (r' + R)\sin\theta\big\} + j\big\{(r' + R)\cos\theta - (x' + X)\sin\theta\big\}\Big]\frac{\bar{N}\,t\,p}{I''^2} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (6)$$

General Expression for the Current in the Shunt Circuit.

The current produced in the shunt for a potential difference V at its terminals will be $c = (r' + j\,x')\frac{V}{I'^2}$, when no E.M.F. is induced by the main current or external field.

Hence—

$$c = \left[\frac{r_1 + r_2 + K^2 r_1^2 r_2 p^2}{1 + K^2 r_1^2 p^2} + \frac{M_b^2 r_3 p^2}{I_3^2} + j\left\{\frac{L - K r_1^2 + L K^2 r_1^2 p^2}{1 + K^2 r_1^2 p^2} - \frac{M_b^2 L_3 p^2}{I_3^2}\right\} p\right]\frac{V}{I'^2}.$$

With a potential difference V at the shunt terminals and a current C(cos $\phi + j$ sin ϕ) in the main coils we have—

$$\begin{aligned} c &= (r' + j\,x')\frac{V}{I'^2} + \Big[-\big\{(x' + X)\cos\phi + (r' + R)\sin\phi\big\} \\ &\qquad + j\big\{(r' + R)\cos\phi - (x' + X)\sin\phi\big\}\Big]\frac{M\,p\,C}{I''^2} \\ &= \frac{r'V}{I'^2} - \frac{\big\{(x' + X)\cos\phi + (r' + R)\sin\phi\big\}M\,p\,C}{I''^2} \\ &\qquad + j\left[\frac{x'V}{I'^2} + \frac{\big\{(r' + R)\cos\phi - (x' + X)\sin\phi\big\}M\,p\,C}{I''^2}\right] \quad . \; . \quad (7) \end{aligned}$$

In this case the power as read by the wattmeter—

$$w' = r \times \text{scalar product of C and } c\,;$$

or—

$$w' = r\,C\left[\frac{r'\cos\phi + x'\sin\phi}{I'^2}V - \frac{x' + X}{I''^2}M\,p\,c\right] \quad . \; . \; . \quad (8)$$

The assumption is here made that there are no eddy currents—or at any rate, that their only manifestation is in modifying the impedance of the shunt.

If, on the other hand, we have a potential difference V on the shunt circuit and a flux N $+ j$ N′ cutting it, we have—

$$\begin{aligned} c &= \frac{r'V}{I'^2} - \frac{N(x' + X) + N'(r' + R)}{I''^2}\,t\,p \\ &\qquad + j\left[\frac{x'V}{I'^2} + \frac{N(r' + R) - N'(x' + X)}{I''^2}\,t\,p\right] \quad . \; . \; . \quad (9) \end{aligned}$$

or—

$$c=\frac{r'}{I'^2}V-\frac{lp}{I''^2}(N\,x''+N'\,r'')+j\left[\frac{x'}{I'^2}V+\frac{lp}{I''^2}(N\,r''-N'\,x'')\right]\quad(10)$$

where $r''=r'+R$ and $x''=x'+X$.

Stationary Field.

The stationary field produces two effects : In the first place it is one of the component quantities of the force or torque of the instrument, and in the second place it may induce currents in the shunt winding. The total stationary flux entering the shunt coil is—

$$\frac{M\,C+M_b\,c'}{t}$$

where c' is the resultant eddy current. This current is caused by the E.M.F. e induced by the fields due to the main and shunt coils.

Hence—

$$c'=e\,Y_3=j\left\{M_a\,\hat{C}+M_b\,\hat{c}\right\}p\,Y_3$$

and the flux—

$$=\frac{M\,C}{t}+j\left\{M_a\hat{C}+M_b\,\hat{c}\right\}\frac{M_b}{t}p\,Y_3.$$

If $\hat{C}=C(\cos\phi+j\sin\phi)$ and $\hat{c}=c+j\,c_1$

$$\hat{N}=\frac{M\,C}{t}\cos\phi-\frac{M_b\,p}{I_3^2\,t}\left\{M_a\,C\,(x_3\cos\phi+r_3\sin\phi)+M_b\,(x_3\,c+r_3\,c_1)\right\}$$
$$+j\left[\frac{M\,C}{t}\sin\phi-\frac{M_b\,p}{I_3^2\,t}\left\{M_a\,C\,(x_3\sin\phi-r_3\cos\phi)+M_b\,(x_3\,c_1-r_3\,c)\right\}\right]\quad(11)$$

In strictness the relation between the shunt current and $\hat{N}$ would have to be rigorously examined, but as the shunt current never differs appreciably from $\frac{V}{r}$ this value may be taken with amply sufficient accuracy.

Hence—

$$\hat{N}=\frac{M\,C}{t}\cos\phi-\frac{M_b\,p}{I_3^2\,t}\left\{M_a\,C\,(x_3\cos\phi+r_3\sin\phi)+\frac{M_b\,x_3\,V}{r}\right\}$$
$$+j\left[\frac{M\,C}{t}\sin\phi-\frac{M_b\,p}{I_3^2\,t}\left\{M_a\,C\,(x_3\sin\phi-r_3\cos\phi)-\frac{M_b\,r_3\,V}{r}\right\}\right].\quad(12)$$

If q is the co-ordinate, the variation of which produces the deflection, the torque or force is proportional to the scalar product of $\hat{c}$ and $\frac{\delta\hat{N}}{\delta q}$, and hence of $\hat{c}$ and $\hat{N}$.

In finding the value of the shunt current we may take formula (10) and insert the values of N and N′ from the result just obtained. In doing so, however, the component of $\hat{N}$, due to the eddy currents pro-

duced by the shunt must be omitted, as the effect of this on the shunt current has already been taken into account.

Hence we have for the shunt current—

$$\hat{c} = \frac{r}{I'^2} V - \left\{ M\,(x'' \cos\phi + r'' \sin\phi) - \frac{M_a M_b p}{I_3^2} \left[x''\,(x_3 \cos\phi + r_3 \sin\phi) + r''\,(x_3 \sin\phi - r_3 \cos\phi) \right] \right\} \frac{C p}{I'^2}$$

$$+ j \left[\frac{x'}{I'^2} V + \left\{ M\,(r'' \cos\phi - x'' \sin\phi) - \frac{M_a M_b p}{I_3^2} \left[r''\,(x_3 \cos\phi + r_3 \sin\phi) - x''\,(x_3 \sin\phi - r_3 \cos\phi) \right] \right\} \frac{C p}{I''^2} \right] \quad . \quad . \quad . \quad . \quad . \quad (13)$$

and, finally, for the wattmeter reading—

$$w' = \frac{r' t}{M} (\hat{N}\,\hat{c})$$

or—

$$w' = \frac{r'^2}{I'^2} w + \frac{r'\,x'}{I'^2} W \sin\phi - M\,p\,\frac{r'\,x''}{I''^2} C^2$$

$$- \left[\frac{r'}{I'^2}\,\frac{M_a M_b}{M}\,\frac{p}{I_3^2} \left\{ (x_3 r' - r_3 x') \cos\phi + (r_3 r' + x_3 x') \sin\phi \right\} \right.$$

$$- \frac{M_b^2 p^2}{r I_3^2}\,\frac{r'}{I''^2} \left\{ (x_3 x'' + r_3 r'') \cos\phi + (x_3 r'' - r_3 x'') \sin\phi \right\}$$

$$\left. + \frac{M_a M_b^3 p_3}{M\,r\,I_3^2}\,\frac{r'}{I'^2} (x'' \cos\phi + r'' \sin\phi) \right] W + \left\{ 2\,x_3 - \frac{M_a M_b p}{M} \right\} \frac{M_b M_b p^2}{I_3^2}\,\frac{r'\,x''}{I''^2} C^2$$

$$- \frac{M_b p r'}{M\,r\,I'^2 I_3^2} (x_3 r' - r_3 x'_3) V^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

A complete discussion of this result would take up considerable space, but the principal features may be mentioned.

If M, M_a, and M_b are all zero the expression reduces to the standard form. The third term corresponds to that before obtained for the effect of mutual inductance between the coils.

For a given frequency the formula may be written—

$$w' = a\,w - W\,(b \cos\phi + c \sin\phi) + m\,C^2 + n\,V^2 \quad . \quad . \quad . \quad . \quad (15)$$

where, however, *a*, *b*, *c*, *m*, and *n* may vary with the position of the moving coil. For a zero-reading instrument they are, of course, constant.*

* Since the above was written, Dr. E. B. Rosa has called the writer's attention to his valuable paper on "The Compensated Two-circuit Electrodynamometer," Bulletin, Bureau of Standards, Washington, No. 48, in which he has made calculations on somewhat the same lines as the above. Although, however, his investigations have some bearing on wattmeters, they are principally concerned with current and potential difference measurements.

Effect of Wave-form.

In the preceding theory a sinusoidal wave-form has been assumed throughout, but as wave-forms frequently differ considerably from the sine curve, some consideration as to the magnitude of the corrections in such cases is desirable. In order to avoid unnecessary complication, however, eddy currents will be assumed absent, and mutual induction as being usually of much less importance than shunt inductance, will be dealt with separately.

Let—

$$V = \Sigma V_n \sin n (p t - \theta_n),$$

and—

$$C = \Sigma C_n \sin n (p t - \Psi_n),$$

where n is the order of the harmonic, V_n and C_n the amplitude of the successive harmonics of potential difference and current respectively, and θ_n and Ψ_n their corresponding phases.

Then—

$$w = \Sigma \bar{V}_n \bar{C}_n \cos n (\Psi_n - \theta_n) = \Sigma \bar{V}_n \bar{C}_n \cos \phi_n \quad . \quad . \quad . \quad (16)$$

where—

$$\phi_n = n (\Psi_n - \theta_n),$$

or is the lag of the current harmonic behind the corresponding potential difference.

The wattmeter reading will be obviously—

$$w' = \Sigma \frac{r}{I_n} \bar{V}_n \bar{C}_n \cos (\phi_n - a_n) \quad . \quad . \quad . \quad . \quad . \quad (17)$$

where I_n is the impedance of the shunt to the harmonic of order n, and a_n the corresponding angle of lag in the shunt circuit.

Hence—

$$\cos a_n = \frac{r}{I_n},$$

and—

$$w' = \Sigma \bar{V}_n \bar{C}_n \cos a_n \cos (\phi_n - a_n) \quad . \quad . \quad . \quad . \quad . \quad (18)$$

Expanding—

$$\begin{aligned} w' &= \Sigma V_n \bar{C}_n \left\{\cos^2 a_n . \cos \phi_n + \sin a_n . \cos a_n . \sin \phi_n\right\} \\ &= \Sigma \bar{V}_n \bar{C}_n \left\{\cos \phi_n + \sin a_n . \sin (\phi_n - a_n)\right\} \\ &= w + \Sigma \bar{V}_n \bar{C}_n \sin a_n . \sin (\phi_n - a_n) \\ &= w + T p \Sigma \frac{n}{1 + n^2 T^2 p^2} \bar{V}_n \bar{C}_n \left\{\sin \phi_n - n T p \cos \phi_n\right\}. \end{aligned}$$

Hence—

$$w = w' - T p \Sigma \frac{n}{1 + n^2 T^2 p^2} V_n \bar{C}_n (\sin \phi_n - n T p \cos \phi_n) \quad . \quad . \quad (19)$$

If $n\,T\,p$ is small in comparison with unity—

$$w = w' - T\,p\,\Sigma\,n\,\bar{V}_n\,\bar{C}_n \sin\phi_n, \quad . \quad . \quad . \quad . \quad . \quad . \quad (20)$$

which is sufficiently accurate for most purposes. The full expression may also be written in the form—

$$w = w' - T\,p\,\Sigma\,n\,\bar{V}_n\,\bar{C}_n \sin\phi_n + T^2 p^2\,\Sigma\,\frac{n^2}{1 + n^2 T^2 p^2}\,\bar{V}_n\,\bar{C}_n$$
$$(n\,T\,p \sin\phi_n + \cos\phi_n), \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (21)$$

in which the third term is obviously small in comparison if $n\,T\,p$ is small compared with unity.

Using the expression—

$$w = w' - T\,p\,\Sigma\,n\,\bar{V}_n\,\bar{C}_n \sin\phi_n,$$

and taking a single wave of order n,

$$w = w' - n\,T\,p\,w \sin\phi,$$

which reduces to the standard form when $n = 1$. The correction is thus proportional to n, as is obvious from its proportionality to p.

Limiting Values for the Correction.

If current is in phase with the potential difference, $\phi_n = 0$, and—

$$w = w' + T^2 p^2\,\Sigma\,\frac{n^2}{1 + n^2 T^2 p^2}\,\bar{V}_n\,\bar{C}_n \quad . \quad . \quad . \quad . \quad . \quad . \quad (22)$$

On the other hand, if the circuit is very inductive $\phi_n = 90°$, and—

$$w = w' - T\,p\,\Sigma\,n\,\bar{V}_n\,\bar{C}_n,$$

the third term being neglected. In this case, however, if x is the reactance of the circuit to the fundamental frequency—

$$\bar{C}_n = \frac{\bar{V}_n}{n\,x},$$

and—

$$n\,\bar{V}_n\,\bar{C}_n = \frac{\bar{V}_n^2}{x}.$$

Hence—

$$w = w' - T\,p\,\frac{\bar{V}^2}{x}$$

since—

$$\bar{V}^2 = \Sigma\,\bar{V}_n^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (23)$$

This result is interesting, as it shows that the error in the reading of a wattmeter on a very inductive load is independent of the wave-form.

Again, if x is a capacity reactance—

$$\bar{C}_n = \frac{n\,\bar{V}_n}{x}$$

and—

$$n \, V_n \, \bar{C}_n = n^2 \, \frac{\bar{V}_n{}^2}{x}.$$

Hence—

$$w = w' + \frac{T\,p}{x} \, \Sigma \, n^2 \, V_n{}^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (24)$$

In the case of power measurements on condensers, therefore, unless the successive harmonics become rapidly smaller, the error will be greatly magnified.

As an indication of the amount of error to be expected in special cases, we may take wave-forms of definite shape, such as an absolutely rectangular or flat-topped curve, or a triangular curve.

The equation of the former may be written—

$$V = \frac{4}{\pi} \, \hat{V} \, \Sigma_0^\infty \, \frac{\sin n\,p\,t}{n}{}^{*}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (25)$$

while that of the latter is—

$$V = \frac{8}{\pi^2} \, \hat{V} \, \Sigma_0^\infty \, (-1)^{\frac{n-1}{2}} \, \frac{\sin n\,p\,t}{n^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (26)$$

In both cases n must have odd values only.

Case I.—V and C both rectangular—

$$V = \frac{4}{\pi} \, \hat{V} \, \Sigma_0^\infty \, \frac{\sin n\,p\,t}{n} \quad \text{and} \quad C = \frac{4}{\pi} \, \hat{C} \;\; \Sigma_0^\infty \, \frac{\sin n\,(p\,t - \phi)}{n}.$$

Then—

$$\hat{V}_n = \frac{4}{\pi\,n} \, \hat{V} \quad \text{and} \quad \bar{V}_n = \frac{2\sqrt{2}}{\pi\,n} \, \bar{V} \quad \text{since} \quad \bar{V} = \hat{V}.$$

Similarly—

$$\bar{C}_n = \frac{2\sqrt{2}}{\pi\,n} \, \bar{C} \quad \text{and} \quad \phi\,n = n\,\phi.$$

Hence—

$$w = w' - \frac{8}{\pi^2} \, T\,p\,W \, \Sigma_0^\infty \, \frac{\sin n\,\phi}{n} + \frac{8}{\pi^2} \, T^2\,p_2\,W \, \Sigma \, \frac{n\,T\,p \sin n\,\phi + \cos n\,\phi}{1 + n^2\,T^2\,p^2} \quad (27)$$

If—

$$\phi = 0$$

$$w = w' + \frac{8}{\pi^2} \, T^2\,p^2\,W \, \Sigma_0^\infty \, \frac{1}{1 + n^2\,T^2\,p^2},$$

while if $\phi = \frac{\pi}{2}$

$$w = w' + \frac{8}{\pi^2} \, T\,p\,W \left\{ \Sigma_0^\infty \, \frac{\sin n\,\frac{\pi}{2}}{n} - T^2\,p^2 \, \Sigma \, \frac{n \sin n\,\frac{\pi}{2}}{1 + n^2\,T^2\,p^2} \right\}.$$

* In what follows $\hat{V}$ and $\hat{C}$ are the maximum values of V and C, not the vectors.

If, in these expressions, $T p$ is small compared with unity, and the higher harmonics are absent—

$$w = w' + \frac{8}{\pi^2} T^2 p^2 W \times \text{the number of harmonics at unity power factor};$$

$$w = w' - \frac{8}{\pi^2} T p W (1 - \tfrac{1}{3} + \tfrac{1}{5} - \tfrac{1}{7} + \ldots) = w' - \frac{2}{\pi} T p W$$

at zero power factor. The correction is therefore less than that for a pure sine wave.

Case II.—V and C both triangular—

$$V = \frac{8}{\pi^2} \hat{V} \Sigma_0^\infty (-1)^{\frac{n-1}{2}} \frac{\sin n p t}{n^2},$$

and—

$$C = \frac{8}{\pi^2} \hat{C} \Sigma_0^\infty (-1)^{\frac{n-1}{2}} \frac{\sin n (p t - \phi)}{n^2}.$$

Then—

$$\hat{V}_n = \frac{8}{\pi^2 n^2} \hat{V} \text{ and } \bar{V}_n = \frac{8}{\pi^2 n^2} \sqrt{\frac{3}{2}} \bar{V}.$$

Hence—

$$w = w' - \frac{96}{\pi^4} T p W \Sigma_0^\infty \frac{\sin n \phi}{n^3} + \frac{96}{\pi^4} T^2 p^2 W \Sigma_0^\infty \frac{n T p \sin \phi + \cos n \phi}{n^2 (1 + n^2 T^2 p^2)} \quad (28)$$

If—

$$\phi = 0,$$

$$w = w' + \frac{96}{\pi^4} T^2 p^2 W \Sigma_0^\infty \frac{1}{n^2 (1 + T^2 p^2 n^2)},$$

while if—

$$\phi = \frac{\pi}{2},$$

$$w = w' - \frac{96}{\pi^4} W T p \left\{ 1 - \frac{1}{3^3} + \frac{1}{5^3} - \ldots \mp T^2 p^2 \Sigma \frac{(-1)^{\frac{n-1}{2}}}{n (1 + n^2 T^2 p^2)} \right\}$$

$$= w' - \frac{3}{\pi} W T p \pm \frac{96}{\pi^4} W T^3 p^3 \Sigma \frac{(-1)^{\frac{n-1}{2}}}{n (1 + n^2 T^2 p^2)}.$$

Case III.—Potential difference wave triangular, current wave rectangular.

Here—

$$V = \frac{8}{\pi^2} \hat{V} \Sigma (-1)^{\frac{n-1}{2}} \frac{\sin n p t}{n^2},$$

and—

$$C = \frac{4}{\pi} \hat{C} \Sigma \frac{\sin n (p t - \phi)}{n},$$

$$\bar{V}_n = \frac{64}{\pi^2 n^2} \sqrt{\frac{3}{2}} \bar{V}, \quad C_n = \frac{2\sqrt{2}}{\pi n} \bar{C},$$

and—

$$n\,V_n\,\bar{C}_n = n^2\,\frac{\bar{V}_n^{\,2}}{x}.$$

Hence—

$$w = w' + \frac{T\,p}{x}\,\Sigma\,n^2\,V_n^{\,2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (24)$$

In the case of power measurements on condensers, therefore, unless the successive harmonics become rapidly smaller, the error will be greatly magnified.

As an indication of the amount of error to be expected in special cases, we may take wave-forms of definite shape, such as an absolutely rectangular or flat-topped curve, or a triangular curve.

The equation of the former may be written—

$$V = \frac{4}{\pi}\,\hat{V}\,\Sigma_0^\infty\,\frac{\sin n\,p\,t}{n}\text{*}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (25)$$

while that of the latter is—

$$V = \frac{8}{\pi^2}\,\hat{V}\,\Sigma_0^\infty\,(-1)^{\frac{n-1}{2}}\,\frac{\sin n\,p\,t}{n^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (26)$$

In both cases n must have odd values only.

Case I.—V and C both rectangular—

$$V = \frac{4}{\pi}\,\hat{V}\,\Sigma_0^\infty\,\frac{\sin n\,p\,t}{n} \quad \text{and} \quad C = \frac{4}{\pi}\,\hat{C}\,\Sigma_0^\infty\,\frac{\sin n\,(p\,t - \phi)}{n}.$$

Then—

$$\hat{V}_n = \frac{4}{\pi\,n}\,\hat{V} \quad \text{and} \quad \bar{V}_n = \frac{2\sqrt{2}}{\pi\,n}\,\bar{V} \quad \text{since} \quad \bar{V} = \hat{V}.$$

Similarly—

$$\bar{C}_n = \frac{2\sqrt{2}}{\pi\,n}\,\bar{C} \quad \text{and} \quad \phi\,n = n\,\phi.$$

Hence—

$$w = w' - \frac{8}{\pi^2}\,T\,p\,W\,\Sigma_0^\infty\,\frac{\sin n\,\phi}{n} + \frac{8}{\pi^2}\,T^2\,p_2\,W\,\Sigma\,\frac{n\,T\,p\,\sin n\,\phi + \cos n\,\phi}{1 + n^2\,T^2\,p^2} \quad (27)$$

If—

$$\phi = 0$$

$$w = w' + \frac{8}{\pi^2}\,T^2\,p^2\,W\,\Sigma_0^\infty\,\frac{1}{1 + n^2\,T^2\,p^2},$$

while if $\phi = \frac{\pi}{2}$

$$w = w' + \frac{8}{\pi^2}\,T\,p\,W\left\{\Sigma_0^\infty\,\frac{\sin n\,\frac{\pi}{2}}{n} - T^2\,p^2\,\Sigma\,\frac{n\,\sin n\,\frac{\pi}{2}}{1 + n^2\,T^2\,p^2}\right\}.$$

* In what follows $\hat{V}$ and $\hat{C}$ are the maximum values of V and C, not the vectors.

If, in these expressions, $\mathrm{T}p$ is small compared with unity, and the higher harmonics are absent—

$$w = w' + \frac{8}{\pi^2}\mathrm{T}^2 p^2 \mathrm{W} \times \text{ the number of harmonics at unity power factor};$$

$$w = w' - \frac{8}{\pi^2}\mathrm{T}p\mathrm{W}(1 - \tfrac{1}{3} + \tfrac{1}{5} - \tfrac{1}{7} + \ldots) = w' - \frac{2}{\pi}\mathrm{T}p\mathrm{W}$$

at zero power factor. The correction is therefore less than that for a pure sine wave.

Case II.—V and C both triangular—

$$\mathrm{V} = \frac{8}{\pi^2}\hat{\mathrm{V}}\,\Sigma_0^\infty (-1)^{\frac{n-1}{2}} \frac{\sin npt}{n^2},$$

and—

$$\mathrm{C} = \frac{8}{\pi^2}\hat{\mathrm{C}}\,\Sigma_0^\infty (-1)^{\frac{n-1}{2}} \frac{\sin n(pt - \phi)}{n^2}$$

Then—

$$\hat{\mathrm{V}}_n = \frac{8}{\pi^2 n^2}\hat{\mathrm{V}} \quad \text{and} \quad \bar{\mathrm{V}}_n = \frac{8}{\pi^2 n^2}\sqrt{\frac{3}{2}}\,\bar{\mathrm{V}}.$$

Hence—

$$w = w' - \frac{96}{\pi^4}\mathrm{T}p\mathrm{W}\,\Sigma_0^\infty \frac{\sin n\phi}{n^3} + \frac{96}{\pi^4}\mathrm{T}^2p^2\mathrm{W}\,\Sigma_0^\infty \frac{n\mathrm{T}p\sin\phi + \cos n\phi}{n^2(1 + n^2\mathrm{T}^2p^2)} \quad (28)$$

If—

$$\phi = 0,$$

$$w = w' + \frac{96}{\pi^4}\mathrm{T}^2p^2\mathrm{W}\,\Sigma_0^\infty \frac{1}{n^2(1 + \mathrm{T}^2p^2n^2)},$$

while if—

$$\phi = \frac{\pi}{2},$$

$$w = w' - \frac{96}{\pi^4}\mathrm{W}\mathrm{T}p\left\{1 - \frac{1}{3^3} + \frac{1}{5^3} - \ldots \mp \mathrm{T}^2p^2\,\Sigma \frac{(-1)^{\frac{n-1}{2}}}{n(1 + n^2\mathrm{T}^2p^2)}\right\}$$

$$= w' - \frac{3}{\pi}\mathrm{W}\mathrm{T}p \pm \frac{96}{\pi^4}\mathrm{W}\mathrm{T}^3p^3\,\Sigma \frac{(-1)^{\frac{n-1}{2}}}{n(1 + n^2\mathrm{T}^2p^2)}.$$

Case III.—Potential difference wave triangular, current wave rectangular.

Here—

$$\mathrm{V} = \frac{8}{\pi^2}\hat{\mathrm{V}}\,\Sigma(-1)^{\frac{n-1}{2}} \frac{\sin npt}{n^2},$$

and—

$$\mathrm{C} = \frac{4}{\pi}\hat{\mathrm{C}}\,\Sigma \frac{\sin n(pt - \phi)}{n},$$

$$\bar{\mathrm{V}}_n = \frac{64}{\pi^2 n^2}\sqrt{\frac{3}{2}}\,\bar{\mathrm{V}}, \quad \mathrm{C}_n = \frac{2\sqrt{2}}{\pi n}\bar{\mathrm{C}},$$

and—

$$\bar{V}_n \bar{C}_n = \frac{128\sqrt{3}}{\pi^3 n^3} W.$$

Hence—

$$w = w' - \frac{128\sqrt{3}}{\pi^3} W T p \Sigma \frac{\sin n\phi}{n^2}$$

$$+ \frac{128\sqrt{3}}{\pi^3} W T^2 p^2 \Sigma \frac{n T p \sin n\phi + \cos n\phi}{n(1 + n^2 T^2 p^2)} \quad . \quad . \quad . \quad . \quad (29)$$

For—

$$\phi = 0,\ w = w' + \frac{128\sqrt{3}}{\pi^3} W T^2 p^2 \Sigma \frac{1}{n(1 + n^2 T^2 p^2)},$$

$$\phi = \frac{\pi}{2},\ w = w' - \frac{128\sqrt{3}}{\pi^3} W T p \Sigma \left(1 - \frac{1}{3^3} + \frac{1}{5^3} - \dots\right)$$

$$+ \frac{128\sqrt{3}}{\pi^3} W T^2 p^2 \Sigma \frac{\pm 1}{1 + n^2 T^2 p^2},$$

$$= w' - 4\sqrt{3} T p W + \frac{128\sqrt{3}}{\pi^3} T^2 p^2 W \ \Sigma \frac{+1}{1 + n^2 T^2 p^2}.$$

The table on page 267 has been calculated out by my assistant, Mr. A. F. Burgess, B.Sc., for a wattmeter having a phase displacement on the fundamental harmonic of 0·001 radian or 0·06 degree. It will be seen that only in the case of the rectangular potential difference wave on a condenser does the correction appreciably exceed that on a sine wave-form. Wattmeters in which the shunt reactance is within the above limit may therefore be used with confidence under almost any practical conditions.

Mutual Inductance.

In the case of mutual inductance between the coils the effect of wave-form is obtained with extreme ease, as the inductive effect depends only upon the current.

For a sine wave—

$$\Delta w = M p \frac{r' x''}{I''^2} C^2, \text{ from (14)}.$$

In all ordinary cases I′ and I″ may be taken as equal to r', and hence—

$$\Delta w = M T p^2 \bar{C}^2,$$

and—

$$\Delta w_n = n^2 M T p^2 \bar{C}_n^2,$$

or—

$$\Delta w = M T p^2 \Sigma n^2 \bar{C}_n^2.$$

But—

$$\bar{C}^2 = \Sigma \bar{C}_n^2,$$

$$\therefore \ \Delta w = M T p^2 C^2 \frac{\Sigma n^2 \bar{C}_n^2}{\Sigma \bar{C}_n^2}.$$

EFFECT OF WAVE-FORM ON WATTMETER CORRECTION FOR SHUNT INDUCTANCE.

Case.	Wave-form.		$u = \frac{w - w'}{W}$.	
	Voltage.	Current.	$\phi = 0$.	$\phi = \frac{\pi}{2}$.
	Sine ...	Sine	0	$-1{\cdot}00 \times 10^{-3}$
I.	Rectangular	Rectangular	$0{\cdot}81 \times 10^{-6} \times$ No. of Harmonics	$-0{\cdot}62 \times 10^{-3}$
II.	Triangular	Triangular	$1{\cdot}2 \times 10^{-6}$	$-0{\cdot}96 \times 10^{-3}$
III.	Triangular	Rectangular	$0{\cdot}68 \times 10^{-6}$	$-0{\cdot}82 \times 10^{-3}$
IV.	Rectangular	Condenser $\left(\frac{4}{\pi}\hat{V} K p \Sigma \sin n p t\right)$	—	$0{\cdot}81 \times 10^{-3} \times$ No. of Harmonics
V.	Rectangular	Inductance $\left(\frac{4}{\pi}\frac{\hat{V}}{L p} \Sigma \frac{\sin n p t}{n^2}\right)$	—	$-0{\cdot}97 \times 10^{-3}$
VI.	Triangular	Condenser $\left(\frac{8}{\pi^2} \hat{V} K p \Sigma (-1)^{\frac{n-1}{2}} \frac{\sin n p t}{n}\right)$	—	$-1{\cdot}20 \times 10^{-3}$
VII.	Triangular	Inductance $\left(\frac{8}{\pi^2}\frac{\hat{V}}{L p} \Sigma (-1)^{\frac{n-1}{2}} \frac{\sin n p t}{n^3}\right)$	—	$-1{\cdot}01 \times 10^{-3}$

It follows, therefore, that the error due to mutual induction in any current is obtained by increasing the error due to a sinusoidal current of the same effective value in the ratio of—

$$q = \frac{\Sigma\, n^2 \bar{C}_n^2}{\bar{C}^2} \quad \text{or} \quad \frac{\Sigma\, n^2 \bar{C}_n^2}{\Sigma\, \bar{C}_n^2}.$$

For a rectangular wave—

$$\bar{C}_n^2 = \frac{8}{\pi^2 n^2} C^2,$$

and—

$$q = \frac{8}{\pi^2} \times \text{number of harmonics}.$$

For a triangular wave—

$$\bar{C}_n^2 = \frac{96}{\pi^4 n^4} \bar{C}^2,$$

and—

$$q = \frac{96}{\pi^4} \Sigma \frac{1}{n^2} = \frac{12}{\pi^2}.$$

The mutual induction error therefore may increase considerably with very irregular wave-forms, but as it is usually a quantity of the second order, even this increase rarely makes it of much importance. The error can also be readily determined experimentally during any tests by short-circuiting the potential difference terminals of the wattmeter.

The general conclusion to be derived from the above investigation is that a wattmeter which is free from eddy currents, and in which the resistance exceeds 1,000 ohms per millihenry of equivalent shunt inductance, will never have an error of more than 0·001 in the power factor under practical conditions, except when testing condensers with very irregular wave-forms. As the above condition is very easily secured with ample torque and small power consumption, it may be concluded that a well-made dynamometer wattmeter is superior to any other device for alternate-current power measurement.

ANNUAL DINNER, 1909.

The Annual Dinner of the Institution was held in the Grand Hall of the Hotel Cecil on Wednesday, December 8, 1909. The President, Dr. Gisbert Kapp, presided at a gathering numbering about 300 persons. Among the gentlemen present were: Sir R. D. Powell, Bart., K.C.V.O., President, Royal College of Physicians, Professor W. Grylls Adams, F.R.S., Past-President, Colonel Sir C. B. Euan-Smith, K.C.B., C.S.I., Mr. C. E. Spagnoletti, Past-President, Sir William H. White, K.C.B., F.R.S., Chairman Royal Society of Arts, Dr. Silvanus P. Thompson, F.R.S., Past-President, Sir J. Larmor, D.Sc., F.R.S., Secretary Royal Society, Major-General Sir A. E. Turner, K.C.B., R.A., Sir John Gavey, C.B., Past-President, Mr. R. K. Gray, Past-President, Dr. B. A. Whitelegge, C.B., Chief-Inspector of Factories, Home Office, Sir Edward Thorpe, K.C.B., D.Sc., F.R.S., Principal Government Laboratories, Mr. H. T. Butlin, President Royal College of Surgeons, Sir Philip Magnus, M.P., Secretary Department of Technology, City and Guilds Institute, Dr. R. T. Glazebrook, F.R.S., Past-President, Mr. F. G. Ogilvie, C.B., Secretary Board of Education, Sir R. Hunter, Solicitor General Post Office, Dr. H. T. Bovey, F.R.S., Rector Imperial College of Science, Sir E. G. Burls, C.S.I., late Director-General of Stores, India Office, Mr. W. M. Mordey, Past-President, Mr. H. F. Donaldson, Superintendent, Woolwich Arsenal, Mr. R. Hammond, Honorary Treasurer, Mr. J. A. F. Aspinall, President Institution of Mechanical Engineers, Mr. W. Duddell, F.R.S., Vice-President, Professor C. V. Boys, F.R.S., Gas Referee, Mr. J. W. Jacomb-Hood, Member of Council, Colonel H. C. L. Holden, R.A., F.R.S., Vice-President, Mr. J. Ardron, C.B., Mr. R. A. S. Redmayne, M.Sc., Chief-Inspector of Mines, Dr. W. N. Shaw, LL.D., F.R.S., Director, Meteorological Office, Mr. R. Elliott-Cooper, Vice-President, Institution of Civil Engineers, Mr. C. H. Wordingham, Member of Council, Mr. G. C. Cuningham, General Manager Central London Railway, Mr. R. H. Selbie, General Manager Metropolitan Railway, Mr. F. G. Hallett, Mr. H. Percy Adams, Mr. W. Judd, Member of Council, Mr. J. H. Rider, Member of Council, Mr. J. F. C. Snell, Member of Council, Mr. W. Rutherford, Member of Council, Mr. W. A. H. Walton, Member of Council, Mr. W. M. Morrison, Member of Council, Mr. E. G. Tidd, Chairman Glasgow Local Section, Professor T. Mather, F.R.S., Member of Council, Mr. G. K. B. Elphinstone, Member of Council, Mr. W. W. Cook, Member of Council, Mr. J. E. Taylor, Associate Member of Council,

Mr. H. Human, Associate Member of Council, Mr. E. Russell-Clarke, Associate Member of Council.

The PRESIDENT gave the toasts of "His Majesty the King," and of "Her Majesty Queen Alexandra, His Royal Highness the Prince of Wales, the Princess of Wales, and the other members of the Royal Family."

Sir WILLIAM WHITE, K.C.B., in proposing the toast of the Institution, said that the Institution, which was one of the youngest, was also one of the most remarkable and the most useful of the great engineering institutions in this country. In the first twenty-eight years of its existence its membership had risen to 3,250, and in the next ten years these numbers, which now stood at 6,100, had nearly doubled, numbers which exceeded those of any other British institution excepting those of the parent body, the Institution of Civil Engineers. In regard to the standard of qualifications for admission, the Council had had the advantage of the experience of the older bodies, and they had availed themselves of it to the fullest extent. The Institution was also distinguished from the older societies by having Local Sections. This experiment had been tried some years ago in a society with which the speaker had been connected, but in this case the experiment was not successful; under the wise guidance of the Council the Local Sections of the Institution of Electrical Engineers had prospered, and they had been a means of strengthening the Institution. The President in his inaugural address had expressed the very fine idea that electrical engineering was essential to all other branches of engineering, and was entwined with them. As long as that characteristic was maintained this Institution would have the good wishes of the members of all other engineering societies. He had always pictured to himself engineering as a noble tree, with its roots striking deep down into the soil of science, with one great central trunk and idea, the idea being to use the great forces of Nature for the benefit and service of mankind; the branches were constantly ramifying and parting into fresh shoots, in new directions which developed into great, strong limbs and bore their fruit and blessed the nations. All branches of engineering were closely related to one another, and they were all bound together. The artificial lines of demarcation which are so often the curse of industry, forcing upon men limits that Nature never meant them to observe, could never be maintained in the world of engineering. The Institution had now found a home of its own, and no body of men rejoiced more in the prosperity of the Institution than the Council of the Institution of Civil Engineers.

The PRESIDENT: Sir William White, my Lords, and Gentlemen, we must all feel with keen appreciation the kind words which the proposer of the toast has said about our Institution. It is indeed very valuable to get encouragement from such a quarter—from a prominent member of the Institution of Civil Engineers, which is the very first Institution in the world as regards applied science. We have always tried to follow in the footsteps of the Civil Engineers. Their aim of making use of the

forces of Nature for the convenience of man is ours also, but in many cases we cannot make use of those forces directly. We must put our services at the disposal of men in other professions, especially the members of the Institutions of Civil and Mechanical Engineers. We are really their willing helpmates, and glad that they employ us. Electrical engineering is, in fact, a kind of industrial mascot—herself comely but poor, but very willing to work for others, and bringing prosperity to others. Now, gentlemen, who is most ready to employ a servant who will bring him prosperity? The man who lacks prosperity most. England, however, happily does not contain many industries which lack prosperity. Some of you gentlemen say "Oh, oh!" but let me beg of you not to be influenced by a passing phase in our industrial life. Industry has its ups and downs. We happen to be now at the bottom of the wave; in another few years we shall be where we were a few years ago, namely, at the top, and England has on the whole been at the top. It has been at the top at a time when our great leaders had no need to trouble about science. They had founded their business at a time when their American and European rivals were yet babies in long clothes. There was no foreign competition, there was not much need for science; there were no technical universities. They had the old-fashioned system of a manager or leader of a business taking apprentices or premium pupils, and educating them; and these in their turn took to this lucrative business of taking premium pupils. And so everything went on happily; the business grew, they made money, and everybody was satisfied. But, gentlemen, this condition could not go on for ever. There are other nations which have the ambition to do something in the industrial world. And so they began to make efforts in that direction, but they saw that it was hardly possible to compete with the well-established, strong English firms unless they had a new weapon in their hands, and that new weapon was Science. We see for this reason America establishing Technical Universities and Laboratories, which are equipped with a munificence which you do not find anywhere else. We see Germany and Switzerland—poor countries at that time—establishing so-called Technical High Schools, where the future leaders of industry should be trained and steeled for their combat with their English and much stronger rivals. On the Continent and in America, Science, and especially applied Science, is appreciated to an enormous extent—I might almost say that sometimes it strikes me it is over appreciated. For instance, when I hear of an American Railway Company advertising for train-men and putting in the advertisement that "Graduates of a University will be preferred," I think that is going rather too far. But it is certainly an example of high appreciation of applied science. The latest phase of that we see in electricity. Electricity is a science, and our foreign rivals, who have all along looked to science generally to help them, look now more particularly to electricity to help them also. Electrical Engineering is with our foreign rivals no longer the poorly clad mascot that she once was;

they had so much need of her that they gladly paid well for her services and thus she became a great lady, distributing bounties to her retainers; or in common language, good dividends to her shareholders. What about this mascot in England? I am afraid she is not quite so well dressed yet. And if we come to ask why she should be in more modest circumstances here when she is a 10 per cent. dividend lady in Germany, we have to remember that the great staple industries of England were fully developed long before electricity came on the scene. They are still very strong, and many of the leaders of these great industries think they can do without new-fangled helps, and thus the electrical mascot is not called in. There are, however, exceptions; some of the leaders of our big industries are far-sighted men, who have recognised the advantages of electricity. Sir William White has told us how the application of electricity is of use to so many other trades, and how those trades are beginning to recognise this, but the process is naturally slower than abroad. It is, however, helped on by various circumstances. One of these which appeals to me, as a Professor at a technical university, is the appreciation which applied science now gets at the older universities. You will remember that Oxford has instituted recently an Engineering Chair. Some of the technical professors at the younger universities shook their heads and said, "What does Oxford want with engineering? let it stick to its Latin, Greek, history, and theology, but do not let it invade our special branch." Well, I do not think that is the right view to take. I welcome the fact that Oxford, as Cambridge had before, has an Engineering Chair. Remember that we do not expect either of those old Universities to turn out complete and perfect engineers—no University can do that; but what we do expect them to do is to give their graduates a general idea that engineering is a noble profession, that it is a profession which does good to mankind, and that it is a profession which can increase the earning power of any industry. Now, gentlemen, many of the leaders of our great industries are graduates of Oxford and Cambridge, and it is well that those men should be imbued with the idea of the importance of applied science. They will then be able to select the right men for the detailed work of science, and that is the class which we get from the technical universities. Thus the old universities with their prestige may give us the leaders at the top, and the technical universities, who are more modern but who do equally good work, will give us their lieutenants. Here we have a very strong argument which makes us hope that this process of letting electricity penetrate to various other industries and giving it the opportunity of helping them and increasing their prosperity, will go on at a quicker rate than it has gone up to the present. The old school of let-well-alone, which had grown up in pre-electric days, is gradually being superseded by more progressive elements; and I think it should be our business, as I am sure it is the business and the desire of Institutions like the Mechanicals and the Civils, to foster

this process of imbuing the leaders of the big staple industries of England with the advantages they would reap by adopting electrical methods. But I am afraid there are some, even electrical engineers, who are going the wrong way to work to encourage them. They tell each other—that does not matter so much—but they also tell the world at large—and that matters a great deal—that we are behindhand in electrical engineering. Our last President (Mr. Mordey) has shown by statistics that this is not the case. We are using more electrical energy per head of the population than Germany, and our customers pay less per unit for their energy than the customer has to pay in Germany. "Well," say these Cassandras, "that may be so; you sell more electrical energy, but this energy is made in foreign machines." I can only say that if that statement were literally true it must be a particularly curious kind of machine—a kind which has the knack of becoming invisible as soon as a visitor enters a central station. I have been to a good many central stations, and I have only seldom found there foreign machines. That there are foreign machines in use in English stations I readily admit; but their number is small. About a year ago, and also quite recently, a technical paper published a list totalling about 80,000 k.w. of foreign-made generators at work in English central stations; 80,000 k.w. sounds a great deal, but compare it with the total, which is of the order of 1,000,000 k.w., and you will find it is 8 per cent. Now 8 per cent. is not a great deal. The list was professedly incomplete, but even if we add half as much again, this would only be 12 per cent. That is not so large a figure after all, and certainly not a justification for saying that we are so very low down in the scale. It is certainly not to the advantage of our industry to go and tell the whole world, "Look how very backward we are; we have only supplied 88 per cent. of the machines which England requires, and the remaining 12 per cent. has been supplied by Germany." The fact is, gentlemen, nobody has a monopoly. If there were a monopoly there would be no progress. We all participate in a race for progress, but it is a race where the winning-post is always receding. It is good for us that it should be so, for if we ever reached the winning-post we should cease to work and lose the keenest interest in life. On the whole, we have not done badly in the race. Let me cite a few incidents in this race. Direct driving and the rational use of batteries originated in England; the first electric railway, which was not a toy, was built in Ireland and equipped by an English firm. Now we come to an incident where the foreigner gets credit. Our competitors have given us multipolar dynamos and 3-phase machinery, both of which, after some hesitation—it was not wise of us to hesitate; we ought to have jumped at the chance—but after some hesitation, we adopted. We have been slow in adopting these, but now we are ahead in them, as you will hear to-morrow at the Institution from a paper written by two of our members. If a customer wants any of this kind of goods—multipolar dynamos or

3-phase machin of any kind—he gets better value for his money if he comes to us. he Continent, again, showed the way in 3-phase railway working, a lead which we have never adopted. It also showed the way in single-phase railway working, a lead which we have adopted. Now, for these things we must give foreigners the credit, but we have something to set against it. There has been developed a method of generating electricity—I am proud to say by an honorary member of our Institution—which has completely changed for the better the whole face of electrical engineering—I mean the turbo-generator of the Hon. Charles Parsons. That was taken up very quickly by our rivals, but I do not think they have caught us up yet. On the right side of the ledger is also power transmission. You perhaps will say, "No, the foreigner is ahead in power transmission." I do not think so. These matters we must judge by results; and if you judge them by results—that is to say, by the advantage the customer gets out of it, the industrial, who is eager to adopt electricity —I think we are a little ahead. I do not compare our power-transmission schemes with the gigantic schemes to be found on the Pacific slope, where we have 110,000 volts transmitted over 100 miles and more. Our little island is too densely populated, and coal here is too cheap for that sort of heroic engineering. But when it comes to good sound work on the more modest lines of the Continent of Europe, I think we show equally well. Let me merely cite one instance referring to water-power. There are not many instances to cite, because England has not very much water-power, and it does not always pay to utilise water-power: coal is so cheap here. But let me instance one installation which was opened in the spring of this year, and that is situated at Kinlochleven, where the modest amount of 30,000 H.P. is utilised; and there all the electrical plant, from the generator to the furnace, and all the electric locomotives, cranes, and accessories are British made. But the basis of power work in this country must always be thermic—either the burning of coal, or, what is better still, utilising waste gases. There is a magnificent example of such a utilisation of waste heat at the Bilston steel works. There the blast furnace gas is being used for driving gas engines; the gas engines drive dynamos, and the dynamos deliver current for all purposes where current can be used in the works. Amongst those purposes are two magnificent rolling mills, the design and workmanship of which is equal, and perhaps a little superior, to anything you will find on the Continent, and every ounce of material in that works, from the gas engines down to the last switch, was made in Great Britain. A most important advance has been made in the power business by Mr. Merz, of Newcastle and London. This is also a lead which has been quickly taken up by our German rivals, who, I think we can say, are very quick to appreciate a good thing when they see it. Mr. Merz, as you know, is the engineer to three large power companies on the North-east Coast, and he has made an estimate that the

waste gases from the coke ovens alone in that district would supply, night and day, a quarter million horse-power if used to fire steam boilers, and a third of a million horse-power if used in gas engines. Think of it—a third of a million horse-power going night and day. That is a great deal better than any waterfall in Italy or Switzerland. And, moreover, to utilise it, costs a great deal less money. You may take it that the utilisation of so-called cheap water-power is not at all a cheap thing. We first have to catch the water before we can utilise it, and it is the catching of the water which costs the money. Here the gas is already to hand; we have not to catch it, and therefore a thermic station is, as a rule, generally speaking, about half the price of a water-power station. What has Mr. Merz done? He goes to the coke-oven owner and he arranges with him, to the mutual advantage of the coke-oven owner and of his own power companies, to take off all the gases which the coke-oven owner would otherwise let go as a waste product, and turn it into electricity. This suits the coke-oven owner very well; it suits the power company very well, because it saves coal at their end; and it is an immense boon to the consumer, because in that district the consumer pays for the unit of energy a lower rate than the consumer anywhere else in the world, water-power countries not excluded. Here you have on the side of the balance-sheet again an improvement which is distinctly due to British invention. I have taken up too much of your time already, but let me give you one last example. I want to counteract the bad effect which must be the result of a too modest section in our profession always asserting that we are behindhand. I will give you a last example that this is by no means the case. It is perhaps a little aside from engineering as commonly understood, but we engineers ought always to take up with energy and enthusiasm anything where electricity can be made useful to mankind. The example I want to give you is the improvement that electricity can render, and has rendered, to agriculture. After all, we must live and we must eat, and it is the soil which feeds us; and anybody who can make a little more grow on the soil is a benefactor to mankind. Our electrical mascot is doing it. Sir Oliver Lodge, a British scientist, has by his practical scientific researches—that is not a contradiction, what is scientific is also practical—enabled an old idea, namely, the stimulating of the growth of plants by electrification, to be taken up in a practical way. About twelve farms are now fitted with this apparatus. By means of electrifying the air over the plants the growth is stimulated, and the average result on the twelve farms is an increase of 30 per cent. in the crops. You will admit that this is a very great step in advance. We do not know whether the land will get exhausted under this very intensive culture. Should it be the case, electricity will also supply the remedy. There are now in Norway, Italy, and other places, enormous works where the nitrogen of the air is burnt and fixed in fertilisers, so that you need only use these electrically produced fertilisers to give back to the land what you have coaxed out of it by static electrification.

Dr. S. P. THOMPSON, F.R.S., in proposing the toast of "Science and Industry," said that Science on the one hand and the Industries on the other hand represented the two sides between which our activities moved. He was privileged to couple with his toast the names of two distinguished men, Professor Sir Joseph Larmor, and Mr. J. A. F. Aspinall. Two hundred years ago, when there was no science of electricity, the great figure in science that dominated scientific thought then, and had continued to dominate the thought of the world, was the Master of the Mint, Sir Isaac Newton, the man of whom his old University in Cambridge never ceased to be proud. He became a member of the Royal Society, and represented Cambridge in Parliament as its member. Two hundred years, or nearly so, afterwards, another very eminent man of science, who also had made his mark in mathematics, the late Sir George Stokes, sat in the Chair of Newton as Lucasian Professor of Mathematics at Cambridge. Stokes became President of the Royal Society and represented his University in Parliament. When he died, only some half a dozen years ago, he was succeeded in his Chair of Mathematics by Sir Joseph Larmor, who had not yet arrived at being President of the Royal Society, but as Secretary and sitting at the right-hand side of the President, had acted as censor and advisor to all those who read papers on electricity or mathematics before the Royal Society. They all hoped one day to see him not only sitting in the Chair of Newton at Cambridge, but sitting in the Chair of the Royal Society, and if he cared for politics, perhaps representing his University in some future Parliament. Turning to Mr. Aspinall, they all realised he was a man who had done great things in mechanical engineering. His Company, the Lancashire and Yorkshire Railway, had laid down that remarkable line from Liverpool to Southport, the first heavy electric railway in this country. Mr. Aspinall represented something more than the Lancashire and Yorkshire Railway; he was there as the President of the Institution of Mechanical Engineers.

Sir JOSEPH LARMOR, F.R.S., Secretary of the Royal Society, in responding on behalf of Science, said he congratulated the Institution on the specially intellectual character of the raw material with which it dealt. The effigy which appeared at the head of every official document of the Institution represented a great man of the last century. Those present were probably tired of hearing that Faraday was one of the greatest mathematicians of all ages, although neither himself nor his contemporaries knew it. It was the function of pure science to lead humanity into sight of the promised land, and then the engineer took up the reins and entered into possession. The practice of electrical engineering was based on scientific principles which were laid down by Faraday and Clerk Maxwell half a century ago. In regard to text-books, he pleaded for a middle course between the theoretical books with the long algebraical formulæ and the engineering books with the huge sheaves of documents at the end of the volume. He was old enough to remember when electrons were in-

vented, and he had lived long enough to see that electrons are a specific for everything in the world which people cannot explain in any other way. When he went into an electrical workshop and saw the compact little masses of iron with sheaves of metallic bristles sticking out of them, and arrangements of copper teeth nicely graduated, he had half an idea that the mode of operation of these things when hitched on to a steam engine, was a much more real representative of what an atom of matter is than any artificial accumulation of electrons. He believed the electrical engineer by the process of evolution had got to the bottom of the matter, that the essence of all transformation of motive power is concentration combined with intensity. Minute electrical motors—minute compared with the terrific amount of energy which they transform, running in tremendously intense fields on account of their close fitting—were much more analogous to what nature does in the atom of matter by the enormously intense concentrated energies which are in the atom of matter. These are much better analogies, more vivid analogies certainly, than artificial constructions made up of electrons of a kind which the human mind is too limited to follow out except in the rudest general representations. He was reminded with regard to these little motors—and once started they would go on for ever if you got a thing without electrical resistance—that if only one of these little metallic bristles gets into the wrong place, it represents an atom of radium. There was a terrific transformation into more elementary atoms such as would frighten anybody but an electrical engineer, and it was much more to the point as an analogy than the abstract thing which we now know so much about. Theoretical physics in its more recondite aspects could only be worked by analogies, and we had yet a great deal to learn from the analogies that were supplied so vividly by the very marvellous electrical machinery which had been evolved during the last twenty years. He had thought for a long time, and for a long time had wished to express his obligation, and he was sure the obligation of most people who cultivated abstract science, to the Institution of Electrical Engineers for one very great help which they provided, namely, the publication of *Science Abstracts*, the bulk of the burden of which was borne by this Institution ; they had depended on the Institution of Electrical Engineers very largely for supplying the acknowledged standard compendium of physical science for which workers in England and America were so much indebted. He could not conclude without saying that in fact *Science Abstracts* was one of the few journals that he looked through from end to end, and he thought every one who was concerned in keeping abreast of physical science was indebted to the Institution for supplying such an admirable résumé of what it was necessary for them to know.

Mr. J. A. F. Aspinall, in responding on behalf of Industries, said it had been admitted that scientific men were not always equal to practical work. He thought that the reproaches which were at one time levelled at us, that we were not educating our young men as well

as the nations of Europe, had gone, and that there was little doubt that our youth were as well trained to-day as any of the young engineers throughout the whole of Europe. In every part of the world they were being turned out in vast quantities, and one sometimes wondered where all the young men who were being so educated were going to find work. He had recently been told that in Cornell University alone there were 1,732 students. When he asked the Professor what became of them he said that most of them were absorbed in America, but that large numbers went to South Africa to take up work which we had created by our acquisition of that country, and that these students were, in consequence of their training, sending the orders for machinery back to the United States. While we were spending our wealth and our men in acquiring these territories the trade of the country was being exploited by men who were not of British nationality. Our young men were good engineers, but we ought to pay attention to the commercial side of education. We were too careless in regard to the men we sent out to America, India, or South Africa. No commercial man should be sent away from this country unless he could properly speak the language in which he was to receive orders for the manufacturers whom he represented. Why should not young men going to South Africa be taught, say, Swaheli or pass an examination in Arabic? By the creation of the Nigerian Railway countries had been opened up as markets for British goods—not electrical goods, but goods of all kinds. Why should the trade with these countries be taken away from us on account of the disability of our commercial men? The Liverpool University in starting a faculty of commerce were doing the right thing in trying to improve the education of our young men. In regard to the electrification of railways, the Liverpool and Southport line had been working for four or five years and had been a success, electrically, financially, and commercially. Each individual case of electrification, however, had to be considered on its own merits, and consideration must be given to the conditions of traffic, country, possibility of future traffic, and character of load. There were many cases in which it would be impossible to electrify the lines with any possible chance of commercial success. On the other hand, there were many great improvements which could be made.

Sir JOHN GAVEY, C.B., proposed the toast of "Our Guests" and referred to the honour enjoyed by this Institution of having had at all its annual gatherings eminent representatives of all the intellectual forces of the Empire.

Colonel Sir CHARLES EUAN-SMITH, K.C.B., responded on behalf of the guests.

JOURNAL

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Proceedings of the Four Hundred and Ninety-eighth Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, S.W., on Thursday evening, December 9, 1909—Dr. GISBERT KAPP, President, in the chair.

The minutes of the Ordinary General Meeting held on November 25, 1909, were taken as read, and confirmed.

Messrs. J. R. Blaikie and H. W. K. Irvine were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Member.

John Cuthbert Wigham.

As Associate Members.

William Alderson.
Frederick Robert Bader.
Leonard Charles F. Bellamy.
George Henry B. Bernard.
Pramatha Narayan Biswas.
John Moor Brewis.
James Fowler Brown.
Peter Conway.
John Allen Cork.
Charles Walter Cox.
Frank Gillespie Cresswell.
H. G. Baker Cresswell, M.A.

As Associate Members—continued.

Neville Denison.
Athel Osman St. John Dixon.
Martyn Ivor Williams Ellis.
Edward Gomersall.
C. E. D. Greenhalgh.
Paul Evelyn Gregson.
Frank L. Henley.
Charles Elisha Hollier.
Arthur Howell.
James Clark Hyde.
Arthur Henry Laurence.
Surendra Nath Mandal.
Henry James Miles.
David Taylor Neill.
Samuel Edmund Packham.
Edgar John Page.
James Scott Pitkeathly.
George Shearing.
Harford George Stephens.
George Denham Vickers.
Richard Waring.

As Students.

Herbrand Leo Crosby.
Bernard Dees.
Gracchus Brown Dent.
Harold Restarick Fisher.
Walter George Ford.
John Pendlebury.
Leslie Hurst Peter.
Francis Edward Robinson.
Denys Reeves Smith.
Morice Ord Teague.
Alan Campbell Towers.
Robert Oliver Udall.
Charles Graham Wells.
Walter Vivian Wright.
Francis Vivian Wythes.

Donations to the *Library* were announced as having been received since the last meeting from E. A. Ashcroft, D. Coyle, The Electrician Printing and Publishing Company, Ltd., Dr. J. Erskine-Murray, The Fidelity and Casualty Insurance Company, N.Y., R. Goldschmidt, Dr. J. Henderson, F. J. O. Howe, E. W. Hulme, W. Maurice, E. W. Moss, E. & F. N. Spon, Ltd., Dr. S. P. Thompson, and H. Williams, to whom the thanks of the meeting were duly accorded.

The following paper (see page 281) was read and discussed: "Notes on Methods and Practice in the German Electrical Industry," by L. J. Lepine and A. R. Stelling, Dipl. Ing., Students.

NOTES ON METHODS AND PRACTICE IN THE GERMAN ELECTRICAL INDUSTRY.

By L. J. LEPINE and A. R. STELLING, Dipl. Ing., Students.

(*Paper received from the* MANCHESTER LOCAL SECTION, *October* 13, *read at Manchester on Dec.* 4, *at London on Dec.* 9, 1909, *and at Birmingham on Jan.* 5. 1910.

Introduction.—The object of this paper is to promote a discussion on certain aspects of the electrical industry in Germany, dealing particularly with the manufacture of electrical machinery.

The question of *power supply* has been dealt with fully in the Inaugural Address of the Past President, Mr. W. M. Mordey,* while *Wiring and Installation Rules* were covered by Mr. Steinthal in his paper, March 8, 1908.†

In this paper it is proposed to enumerate the salient factors in the cheap methods of production which render the Germans such serious competitors in the world's markets; with this aim reference will be made to the following subjects:—

1. The capitalisation of the trade.
2. Internal organisation.
3. External organisation.
4. Works and their systems (methods in manufacture).
5. General features and design of machinery, showing—
   (*a*) Variations from English practice.
   (*b*) Comparison of weights.
6. Scientific experimental work in factories.

THE CAPITALISATION OF THE TRADE.

The financial development of the German electrical industry presents many features of interest and importance. To appreciate the present position of the industry the successive stages of this development should be considered separately in conjunction with their bearing upon the present situation.

Prior to 1899 the industry in Germany was divided up among a great many firms, none of which were as large or as powerful as the present-day leading electrical manufacturers. Even at this early date German financiers seem to have realised the advantages which would accrue from association of interests, and they commenced a policy of

* *Journal of the Institution of Electrical Engineers*, vol. 42, p. 10, 1909.
† Ibid., vol. 41, p. 166, 1908.

amalgamation. With each of the more financially powerful firms was associated a trading or investment company; the majority of the shares in the latter were held by the manufacturing company. With the capital at their disposal the investment companies were enabled to finance supply undertakings, the electrification of tramways, etc., and so obtain markets for the parent manufacturing firm. The remainder of the shares in the investment company were, as a rule, held by syndicates of financiers or by banks. Banks in Germany are of a different constitution to English banks. In the first place their capital is usually much larger than is customary in England, and a large portion of this capital is always at the disposal of the directors for investment in industrial concerns. There are other so-called banks which are purely trading syndicates, and whose capital, or rather financial power derived from their capital, is solely used for the purpose of financing industrial undertakings.

As regards the electrical industry, the principal sphere of action of both wholly industrial banks and deposit banks having an industrial development department was in connection with supply companies and electric tramways or railways. When such a company was floated, the bank or investment syndicate took up or underwrote a certain number of shares. The necessary capital was obtained by the issue of bonds on the share capital of the bank and on the shares already held in other companies. The manufacturing company also took up a number of shares, shares already held being mortgaged for a purpose of obtaining the ready money. Where advances were made to companies for extensions these were redeemed later by mortgages on the new plant or by a new issue of capital.

This system, as will be observed, readily lends itself to reckless speculation. During 1899 and 1900 a boom in electrical engineering led to much speculative promotion of electrical schemes and exaggerated extensions of existing ones; the result was an inevitable reaction. Depositors became alarmed at the investments made by their banks, and two banks, the Dresden and Leipzig Credit Banks, had to go into liquidation. It should be noted that both these institutions were deposit banks. The feeling of insecurity which succeeded caused a set back in all branches of electrical engineering, and we may describe the period from 1901 to the end of 1903 as one of reconstruction and amalgamation. In the first place, several firms had to undergo entire reconstruction, but the investment companies and private financial syndicates enabled other firms to successfully weather the depression. Many of the smaller firms which suffered were absorbed by the larger and more influential ones, and there emerged from this period the three great German combinations of Allgemeine Elektrizitäts Gesellschaft, the Siemens-Schuckert group, and Felten-Guilleaume-Lahmeyer. The amalgamated firms proceeded to strengthen their position and prevent *injurious* competition by completing certain working agreements. At the same time they left certain branches open to competition among themselves, especially those in

which they found rivals in the smaller firms, whose interests were purely local.

During the years that followed, the trade in Germany as a whole slowly recovered. The direct result of the amalgamation and working agreements was that these powerful combinations and their associated syndicates were able to control the market, cause a steadying of prices, and an ultimate recovery of confidence.

The heavy electrical machinery trade in Germany is now almost entirely in the hands of four large companies—the three already mentioned and the Bergmann Company—the latter to a certain extent are a party to these working agreements.

The capital of these firms stands at the figures in Table I.

TABLE I.

	£
A.E.G.	4,200,000 share.
	1,930,000 bond.
Siemens-Schuckert	4,500,000 share.
	990,500 bond.
F. & G.-Lahmeyer	2,750,000 share.
	1,250,000 bond.
Bergmann	1,050,000 share.
	500,000 bond.

The best proof of their success is to be found in the dividends paid by these firms during the last few years. We give the dividends for the last two years in Table II. :—

TABLE II.

	1908.	1907.
A.E.G.	12 per cent.	12 per cent.
Siemens-Schuckert ...	10 ,,	10 ,,
F. & G.-Lahmeyer ...	8 ,,	10 ,,
Bergmann	18 ,,	18 ,,

One great advantage of their large capital is their ability to meet sudden demands caused by the advancement of engineering science, such as the erection of special plant for the construction of turbo-generators.

As another example may be cited the participation of German firms in the Victoria Falls power scheme. Not only have they contributed a large portion of the necessary capital, but they are also erecting special shops for the construction of the generating plant, *i.e.*, 20,000-k.w. sets.

Turning to the investment companies, many of these became entirely merged in manufacturing concerns, and were thus enabled substantially to reduce their capital; others improved their financial position by disposing of their shares in unremunerative concerns and in the opening up of new fields.

A glance at the latest report of one of these investment companies shows that no supply company in which they are interested pays less than 6 per cent. dividend; the investment company themselves pay 10 per cent. dividend on a share capital of £1,600,000.

In the improvement of the trade the material assistance afforded by financial syndicates has been of such value that during 1908 a further step in electrical finance was taken. This was the establishing of two electro-trustee banks (Elektrotreuhandbanken) under the control of the large German electrical companies.

The principal object of these "trustee" banks is to advance to large consumers in the electrical industry the money they may require for beginning and carrying out of costly works. The capital needed for the loans is to be obtained by mortgage bonds, secured in the first place by the stocks held by the bank, and in the second place by the share capital of the latter which is to be invested in trustee stocks. As the shares, however, will most probably be retained by the electric works concerned, the entire business resolves itself into a transaction enabling these companies to raise the funds they need in order to assist and open larger credits to their customers, the formation of separate banks evidently having been decided upon as the most likely method of facilitating the placing of bonds. These facilities for obtaining cash advances are to be extended principally to municipalities and other public bodies, so that the bonds will be to all intents perfectly secure while at the same time these authorities will be encouraged to proceed with any plans for the erection of new or the extension of old electrical plant which they may have under consideration, without the necessity of issuing new loans for that purpose.

The present situation is one which in spite of the general trade depression must be described as satisfactory; electrical undertakings are readily able to find working capital independent of the state of the money market and of the manufacturing industry in general. Looking ahead, developments of a less pleasing nature appear to threaten. The various financial institutions, by providing the manufacturers with working capital and credit, enable them to compete successfully in all markets and render each firm independent of the others where capital is required; but should the activity of the banks be reduced from any cause, or should foreign and local competition become so keen as to cause repeated price-cutting, then the great disadvantages of over-capitalisation will make themselves felt, and the large firms will be driven to the formation of a huge trust with their associated banks as a nucleus, their existing intimate relationship rendering the accomplishment of this all the more easy.

Internal Organisation.

In the offices of the firms in question a bureaucratic rule obtains. The keynote of the whole system is that each man's work is specialised.

Each branch of manufacture is an organisation in itself, having its own drawing office, designing, costing, and clerical staff. Alternating-

current induction motors, alternating-current generators and synchronous motors, direct-current small and large machines, and turbo-generators are treated in separate departments, as are also alternating-current and direct-current instruments, wattmeters and switchgear. There are separate drawing offices for estimating purposes, for transmission schemes, lighting schemes and central station designs.

A publicity department run by University graduates in literature is responsible for the catalogue and journalistic work. This department is officially termed the "literary" or "propaganda" department.

Besides this department and the estimating offices for the home trade, each firm has a foreign department which deals exclusively with inquiries from abroad, and which is in correspondence with the branch offices (outside Germany) and the subsidiary companies. The value of this department cannot be too highly estimated. All these various departments are subject to the "Verwaltung" or central authority, which also deals directly with the employees.

The average technical employee is more highly theoretically trained than in England. All members of the technical staff go through one of the drawing offices; in fact, it is in these departments where all German engineers start on a level footing, the chances of promotion depending chiefly on the quality of their training. Technical employees are usually bound under a contract which is all in favour of the employer. In this contract the employee agrees to publish no technical matter without the consent of his firm, to give no private tuition on technical subjects, nor to divulge any methods of the firm by whom he is employed. Further, all designs which may be patented are the property of his employer. The draughtsman is usually forbidden to enter the shops.

Salaries are kept low; after leaving college the engineer commencing work at about twenty-four years of age receives £6 5s. a month. This increases with machine-like regularity until it reaches the maximum wage for the department. Holidays of more than three days either from head office or from a branch office must be granted by the central authority.

External Organisation.

Each firm's trade in Germany is attended to by the head office and branch offices, while to subsidiary companies with their own branch offices is entrusted the control of their trade with other countries.

In dealing with their home trade the German method of working up connections is thorough. Besides obtaining business by the ordinary methods which are employed in England, they spend considerable sums of money in educating the masses. For instance, the following procedure is employed in districts where electricity is an unknown quantity.

Invitations are sent out to the principal householders to attend a lantern-slide lecture on the benefits to be derived from the application of electricity in the home or factory, and the interest of the population

is thus aroused. The engineer then approaches the local mayor and other officials and persuades them to apply (either alone or in conjunction with other villages, as the case may be) for the necessary grant and powers to finance and erect the plant required. In this way many overland central stations have been erected in which the manufacturers have a pecuniary interest. Not only do they then supply the power plant, but also the whole of the fittings required by the consumers, and this on a very profitable basis.

With regard to European trade, this is developed chiefly by means of subsidiary companies having share capitals varying from £100,000 to £600,000 according to the country. These companies are all provided with branch offices, which are controlled by the subsidiary company financially, but which deal directly with the factory in technical matters.

Again, complete staffs are maintained in the countries outside Europe where many competitive English firms are content to employ agents; often enough the latter have but the faintest ideas on the subject of electricity and its application. It will be seen from this and the foregoing paragraph that German firms are always in a position to treat inquiries from all countries with the utmost consideration, and to furnish very complete tenders which are sure to meet customers' requirements. They make a point of accurately ascertaining these requirements; to put it figuratively, "if a screw is required they are not content with being told the size, they want to see the place into which it is to fit."

As the English firms rarely trouble to send experts to investigate proposed schemes, but are content to let branch managers or agents muddle through as best they can, it is not to be wondered at that German firms obtain so many profitable orders in open competition.

The following figures, taken from Board of Trade returns, will perhaps be of interest; they are given for the last few months:—

TABLE III.

	Electrical Imports to Great Britain from Germany.	Electrical Exports to Germany from Great Britain.
	£	£
May	72,843	3,933
June	89,779	4,494
July	92,708	2,137
August	73,321	881
September	82,313	1,841

These figures show a pretty good average of the trade done between England and Germany, as is evident from Table IV.

TABLE IV.

Electrical Exports of Germany and Great Britain.

	From Germany		From Great Britain	
	To Great Britain.	To other Countries.	To Germany.	To other Countries.
	£	£	£	£
1907	553,882	7,673,118	45,532	3,419.583
1908	712,251	8,394,750	46,873	3,240,249

The sums included in the figures under "Exports to Great Britain" for electrical machinery are, for 1907, £227,991, and 1908, £250,402, these being the largest figures in any one section.

Lamps also account for large amounts, viz., £129,244 and £240,989 respectively, these large figures being accounted for by the advent and popularity of the tantalum lamps.

WORKS AND THEIR SYSTEMS (METHODS IN MANUFACTURE).

One is struck, when passing through the works of all the four large firms already mentioned, by the order and cleanliness which there obtains, though the ventilation leaves much to be desired.

The machinery is most advantageously distributed with regard to light, transport, and the rotation of machining operations. For instance, in the new shop for building 20,000-k.w. sets the scheme is to move stator and rotor along ground and first floor respectively, entering the shop at one end in the rough, and leaving at the other end after testing.

The large machine-erecting shops are also made to serve for advertising purposes in a very effective way. On each large stator or magnet yoke is stencilled its destination and output, so that the visitor or prospective customer is duly impressed in favour of the particular firm as he walks through their shops and finds that his friends or competitors have already placed their orders.

Where narrow and long buildings of four and five storeys are in use, lighting shafts are arranged every 30 ft. or so. The very stringent factory inspection and regulations are responsible for the excellent protective devices on machine tools, these guards being more thorough and efficient than those in the average English works.

Group driving of machines seems to be preferred by most firms, but one of the largest has nothing but independent motor drives.

Each department has its own stores, and the departments are so arranged that a minimum amount of transport is necessary to pass each unit from one stage of manufacture to the next.

The capital at their disposal has enabled these firms to lay down large numbers of special machines, thereby reducing the time taken in machining and the wages of the machinists. German designers work with a view of adapting their designs to suit their machine tools.

Automatic machinery is largely used, as are also turret lathes, but jig-work does not receive the same attention given to it by up-to-date English firms. Large machining plates for portable tools are in evidence. The majority of the machine tools are of American manufacture.

Among the smaller special tools in use we may mention small circular electrically driven files used for slot-broaching and generally taking off odd corners, and electric soldering irons, especially one for sweating commutator connections.

Practically all firms buy their iron and steel castings from outside, but have their own brass and aluminium foundries.

The most striking feature in the works system is the working day. This consists of 18 hours worked in two shifts of 9 hours each with ¼-hour intervals in the middle of each shift and half an hour between the two. Thus the shifts are from 7.0 a.m. to 4.15 p.m., and from 4.45 p.m. to 2.0 a.m. This system has many great advantages; quick delivery is possible without the necessity of high wages and establishment charges due to overtime and "night-shifts," because the rates of pay in the two shifts vary but slightly. Overtime is an unknown quantity, the output per machine tool is doubled, capital charges are consequently reduced, and a larger number of men can be kept in constant employment. We regard this 18-hour day as one of the most important factors of Germany's competitive powers.

The system presents very few technical difficulties in management; the connection between the shifts can be maintained by means of detailed reports and co-operation between the foremen and charge hands of the respective shifts.

The Trades' Unions have acquiesced in this system of double shift, and, moreover, are not likely ever to attack it. It is a system worthy of consideration by English firms, but the opposition of Trades' Unions would probably stand in the way of its adoption.

The labour problem in Germany does not present the difficulties that it does in this country, two factors being mainly responsible for this.

The first is the political nature of most of the Trades' Unions, these Unions not having arisen as a result of evil conditions in the trades as was the case in England. When German industries were established, the examples they had from the previous thirty years in England enabled the Government to commence a series of legislative measures for the protection of the workman; in this way he was assured the many benefits for which his English brother had had to go through troublous times.

To-day the German Unions have achieved much in the way of arrangements for arbitration, but unfortunately their tendencies are

too political to obtain for them the strength of union which as non-political organisations they would possess.

Another variety of Union is that supported by the employers, but this is more of the nature of a benevolent society.

The other factor is the thoughtful legislation on the part of the German Government; the labour question has been tackled in a most scientific way, and measures of great value to the workmen have been made law as a result of thoughtful consideration of the problem arising, without the misery of strikes on the part of the workmen. Strikes there are still, but statistics prove their decrease year by year. The Government cannot control all phases of the question, especially the question of minimum wages, but the laws regarding factory inspection, protective devices on machinery, and the hours and conditions of labour are excellently drawn up. Besides these the laws relating to strikes and arbitration ensure fair treatment to the workmen. The system of labour exchanges has been so widely dealt with in the daily papers that we will not discuss it here.

For the reasons detailed above we do not think Germany will ever have to face such a labour problem as English manufacturers have experienced.

Another important feature in the cheap production is the low rate of wages paid. We have already mentioned the large amount of unskilled labour employed, but even the skilled labourer is paid at an extremely low rate. Thus we find that the average wage for mechanics is 32s., and winders on high-tension stators earn all in all 36s. a week as a maximum. Male winders of small induction motor stators and rotors earn anything up to 30s. a week. Female labour is employed very largely, all the taping of induction motor stators being done by females as well as actual winding of small rotors and direct-current armatures. Small coil forming and magnet windings are of course done by girls. We observed girls working turret lathes, tending automatic machines, testing arc lamps and instruments, and doing many other kinds of work usually done by men in England. We are bound to state that females *can* earn higher wages than those employed in English works, and they possess especial privileges under a very thoughtful legislation.

Piece-work is the rule, with the "Kollonnen-system" in erecting. This system, under which one man is given finished units, a number of assistants and a fixed sum for the erection, out of which all wages are to be paid, is in vogue in England in the machine-tool trade.

As regards individual workmanship, the German electrical engineering firms do not compare favourably with the English; "deep scratch and high polish," careless and untidy taping and stringing of coils and a lack of finish are too often noticeable in work of many first-class firms.

General Features and Design of Machinery.

Almost all German firms insist upon the acceptance of their own specifications, and will rarely if ever depart from these. Under this

system makers stand or fall by their own designs and productions; they do not suffer the annoyance of petty alterations, and the experience of their experts in each branch enables them to supply an adequate article without having to submit to outside individual ideas. However strict a specification may be, bad workmanship will destroy its object.

As regards dynamo electric machinery, an 80° F. rise after a 6 hours' run on full load seems to be the standard figure. Motors are rated to stand 25 per cent. overload for 1 hour, and 40 per cent. for 3 minutes, these overloads varying according to the size of the machines, and not being so high as those offered by some of the English makers.

Direct-current Machines.—The designers differentiate between slow, high, and extra high-speed machines, the latter being classed as "turbo-machinery," and are treated in a separate department. We shall also discuss this class under a separate heading. The line of demarcation between slow and high speeds is 20 m./sec. peripheral speed.

Slow-speed machines are designed with a moderate ratio of iron to copper, and are often fitted with laminated poles. High speed have a larger ratio of iron to copper, and are often fitted with solid poles, either cast in or cut from a steel billet. Crane motors are designed on distinctive lines and form a separate range.

For smaller size of motors up to 40 and 50-B.H.P. cast-iron yokes seem popular. Manufacturers specify high magnetic qualities for this cast iron, and the founders are endeavouring with moderate success to meet such requirements.

On larger sizes cast-in poles find very little favour, the most popular form being laminated poles in a steel yoke.

The practice in winding field coils differs somewhat from the English. Large field coils are wound in three or four layers with ventilating spaces between each layer. Bare strip for interpole winding has not yet been even experimented with, though varnished wire has become practically universal for small size interpole coils. Brass bridges between the main pole-tips are used wherever interpoles are fitted.

Brushgear shows nothing new or interesting except that one firm use sheet-iron stampings exclusively in their brush-holders.

It might be mentioned that the makers do not rely on one or two types of brushgear, some firms possessing from fifteen to twenty different patterns.

End-plates are very crudely designed, they are often too heavy and clumsy, though usually they have the advantage of permitting greater accessibility than do some of the English designs.

Slot insulation varies considerably, but press-spahn and micanite on cloth seem to be the most extensively used materials.

Core plates are still insulated by means of thin layers of paper pressed on to the plates. The plates are held together in almost every case by bolts which are usually insulated where they pass through the laminations.

The practice of cutting down the mica between commutator bars is very prevalent.

Ball bearings are not adopted as standard practice. Taken all round the English direct-current machine shows more modern principles of design, and except for slow-speed haulage motors, with

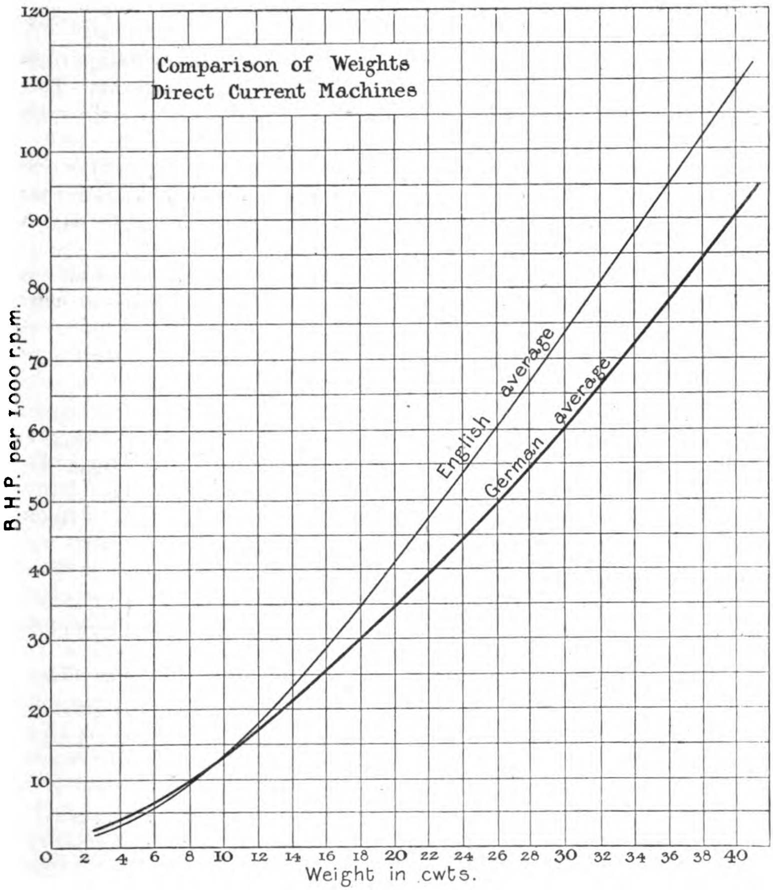

Fig. 1.

which the Germans are very successful, England is in no way behind as regards design and workmanship.

Fig. 1 shows a set of curves plotted for the purpose of comparison of English and German direct-current motors up to 100-B.H.P. with the horse-power per 1,000 revs. per minute plotted against the weights. The motors were all taken on a 440-volt rating. It will be seen that

the average German machines appear to be heavier than the English above 30 B.H.P., but under 30 B.H.P. there is not much difference.

With regard to machines above 100 B.H.P. it was rather difficult to make a comparison owing to the fact that German makers favour slow-speed machinery, while the tendency in England is towards high speed. This variance is the result of the different engine makers' standards in the respective countries. The German high-speed machines are built chiefly for belt driving.

Regarding the electrical design, German firms used to design their machines with very large diameters and short length of core. This practice led to a large ratio of iron to copper in the armatures, the ratio of 2·7 to 1 often being reached.

New designs have been brought out in which the weights of active iron have been reduced, and the ratios of 1·8 to 1 and 2 to 1 are now more prevalent. The saturation of the teeth is carried high, 24,000 lines per square cm. being a good average maximum density.

The following figures based upon averages taken from about 30 machines by various makers may be of interest in comparison with English practice.

German Machines Design Data.

Output, k.w.	0–10	50	150
Output, k.w./1,000 r.p.m.	4·5	70	300
Amp. conductors per cm.-periphery	90–110	150–250	200–280
Current density amps./sq. mm. ...	2·7	2·75	2·8
Air-gap induction lines/sq. cm. ...	7,000	7,500	8,000
$\dfrac{D^2 l\, n \times 10^{-4}}{\text{K.w. at 1,000 r.p.m.}}$ in cm. units ...	100	50–60	40
$\dfrac{\text{Armature iron}}{\text{K.w. per 1,000 r.p.m.}}$ kg.	4·0	2·0	1·5 slow; 1·75 high
$\dfrac{\text{Armature copper}}{\text{K.w. per 1,000 r.p.m.}}$ kg.	2·1	1·1	0·75
Ratio $\dfrac{\text{armature iron}}{\text{armature copper}}$	1·9	1·8	2·0 slow; 2·3 high
Ratio $\dfrac{\text{total active iron}}{\text{total active copper}}$:—			
High speed	1·5	1·5–2·0	2·0–3·0
Slow speed	1·0	1·5–1·8	1·8–2·5

English Machines Design Data.

Output, k.w.	4·65	50	150
Output, k.w./1,000 r.p.m.	4·5	65	300
Amp. conductors per cm.-periphery	130	180	250
Current density amps./sq. mm. ...	4·3	3·4	3·1
Air-gap induction lines/sq. cm. ...	6,700	6,850	7,250
$\dfrac{D^2 l\, n \times 10^{-4}}{\text{K.w. at 1,000 r.p.m.}}$ in cm. units ...	86	58	49

$\dfrac{\text{Armature iron}}{\text{K.w. per 1,000 r.p.m.}}$ kg.	3·0	1·6–2·2	1·3
$\dfrac{\text{Armature copper}}{\text{K.w. per 1,000 r.p.m.}}$ kg.	1·6	0·7–0·75	0·52
Ratio $\dfrac{\text{armature iron}}{\text{armature copper}}$	1·9	2·3–2·9	2·5
Ratio $\dfrac{\text{total active iron}}{\text{total active copper}}$:			
High speed ... ... Slow speed	1·3	1·8	1·6

Note.—Active iron includes poles, pole-shoes, and armature core, but not the magnet yoke. This is done on account of the use of cast-iron yokes by German firms.

Induction Motors.—The tendency in the design of this class of motor appears to be towards long length of core and smaller diameter, possibly on account of their frequent use in driving high-speed centrifugal pumps, etc.; combined with this we find that forced ventilation is becoming more popular, most end-plate type motors being designed for driving a current of air through the motor parallel to the shaft. German engineers have been the first to recognise that vent ducts through the cores parallel to the axis are more efficient than radial ducts, and have begun to adopt this principle.

The motors are very liberally designed with regard to iron, and most designers give a larger ratio of iron to copper than is English practice. This applies to inactive as well as active iron; there are large spaces between stator core and stator case, and there seems plenty of room for the end windings inside the end plates. Small motors without forced ventilation are built without any ventilation holes in the stator case.

The stator windings of small motors are usually of the threaded through type in closed insulating troughs, semi-enclosed slots being invariably used. Steel rods are used to fill out the troughs when winding. All the taping is female labour, and is very often slovenly. It comes as a shock to an English engineer to see the primitive formers and methods in winding in vogue in German works.

Large rotors are often wound with closed circuits as distinct from "squirrel-cage," and rotors are designed with one bar per slot connected in 3, 5, 7, or 11 phases according to size. Slip-rings are almost always gunmetal held on insulated rods with copper-gauze brushes as a general rule. They are arranged between rotor and bearing as standard practice, and are usually fitted with a short-circuiting and brush-lifting device.

The terminals appear to have been very carefully designed, and are arranged on the stator core in a hole cored out of the stator case; this hole is covered as a standard practice with perforated zinc, and the whole presents a very neat finish.

Altogether we are more favourably impressed by German induction

motors than by direct-current motors, though English designs are in no way behind those of Germany.

In Fig. 2 we give a curve of weights against outputs of German and English induction motors.

Below some design data is given of German motors, the figures are taken for standard machines of latest design :—

German Design Data.

Output, H.P.	25	52	150
Output, H.P. at 1,000 r.p.m.	25	80	200
Amp. conductors per cm.-periphery	217	220	200
Air-gap induction lines/sq. cm. ...	5,400	5,600	5,770
$\frac{\text{Core-length}}{\text{Pole-pitch}}$	0·96	1·18	0·98
$\frac{D^2 l\, n\, 10^{-4}}{\text{H.P. per 1,000 r.p.m.}}$ in cm. units ...	65·5	53·5	53·0
$\frac{\text{Kg. iron}}{\text{H.P. at 1,000 r.p.m.}}$	8	4·5	3·3
$\frac{\text{Kg. copper}}{\text{H.P. at 1,000 r.p.m.}}$	2·4	1·36	1·15
Ratio $\frac{\text{active iron}}{\text{active copper}}$	3·3	3·3	2·85

For the purpose of comparison we give a table of data taken from up-to-date English motors, which are lighter than the average :—

English Design Data.

Output, H.P.	25	60	150
Output, H.P. at 1,000 r.p.m.	25	80	200
Amp. conductors per cm.-periphery	225	245	275
Air-gap induction lines/sq. cm. ...	4,400	4,700	4,850
$\frac{\text{Core-length}}{\text{Pole-pitch}}$	0·84	0·94	0·94
$\frac{D^2 l\, n\, 10^{-4}}{\text{H.P. per 1,000 r.p.m.}}$ in cm. units ...	100	70	60
$\frac{\text{Kg. iron}}{\text{H.P. at 1,000 r.p.m.}}$	7	3·5	2·55
$\frac{\text{Kg. copper}}{\text{H.P. at 1,000 r.p.m.}}$	2·4	1·5	1·1
Ratio $\frac{\text{active iron}}{\text{active copper}}$	2·95	2·35	2·30

The characteristics of single-phase commutator motors are so well known from technical journals that we will not enter into any detailed description. The same remarks apply to the windings as in the case of induction motors.

Alternating-current Generators.—Owing to the frequent use of long-

distance transmission and "overland" central station, there is a larger demand for high-tension alternators than in England, and manufacturers have consequently gained large experience in the design of this class of machine. Here again are noticed the long cores and small

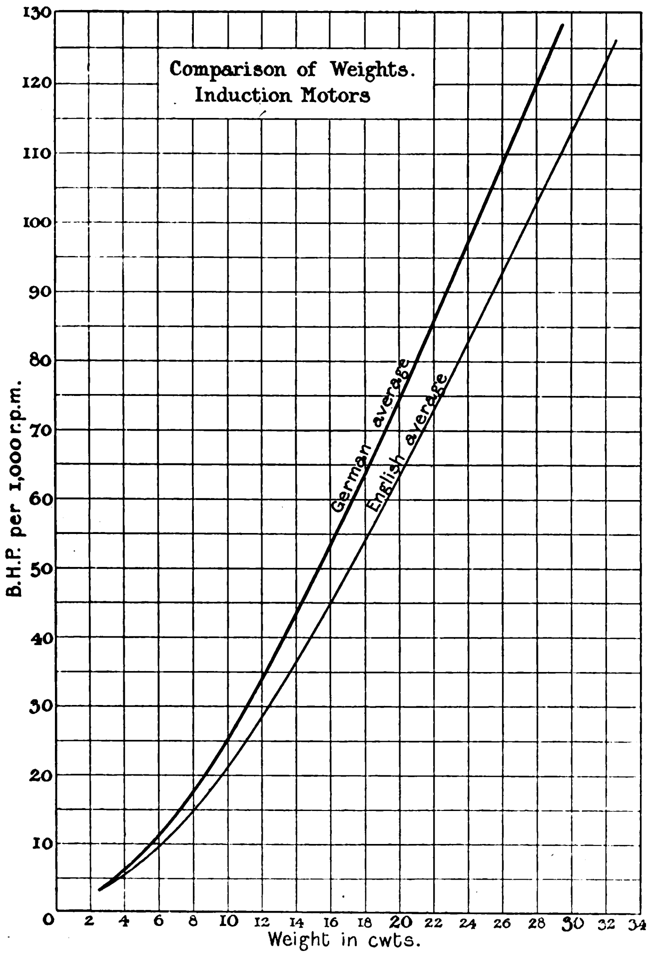

FIG. 2.

diameters, and the axial ventilating ducts. The air-space between stator core and case is very large.

In the design of rotating fields many variations are noticeable. Cast-steel hubs with cast-on pole-pieces are fitted with cast-steel shoes

bolted on, or with laminated pole-shoes either bolted or dovetailed on to the pole-pieces. Solid pole-pieces are dovetailed into the yoke, and laminated pole-pieces are held in the same way. Where laminated shoes are used, they are fitted with phosphor bronze end-shields to support the windings. In a certain instance 4 copper rods were placed in holes through the laminated pole-shoes so near the surface that when turned up the copper was laid bare. These copper rods are short-circuited at their ends by strips into which they are riveted.

For the field-winding square section insulated copper is generally used, though flat strip wound on edge and insulated by layers of paper is often used. For high-speed alternators the hub is built up of forged slabs 3 in. thick, into which the poles are dovetailed. In some cases the poles and hub are built up of slabs, pole-shoes being dovetailed on, and the windings held in place by special rings and wedges. In one interesting case, that of an 8-pole alternator 8 or 9 ft. diameter, and consequently worthy of being classed as a turbo-alternator, the whole magnet, yoke, poles, and pole-shoes are formed of slabs cut from solid forgings to the required shape. Eccentricity of the pole-shoes is obtained as follows:—

Grooves 2½ in. wide are milled along the pole-faces, that is to say, one groove in each slab. In this groove laminations are placed whose outer radius is eccentric to the stator bore.

The field windings are made as follows:—

Copper strip is wound on edge on a mandrel so designed that the turns are too long in the axis parallel to the shaft. The turns are cut forming two U-shaped pieces, and are then placed on the pole (which has been packed with insulation to the exact shape required), alternately with sheets of insulation in such a manner that one end of each of two adjacent coils overlaps the other without insulation, the pressure being sufficient to give good contact. Thus a complete circuit is formed. The coils are pressed against the pole-tips by means of wedges, and V-shaped pieces between the poles take up the component of the centrifugal force which would tend to pull the coils apart. The whole forms a remarkably solid and simple job.

The wire for the high-tension windings, and indeed for all large machines is baked thoroughly before using, and kept in a warm dry store-room until required. Mica on cloth forms the chief slot insulation, the layers of conductors in high-tension work being wound in separate tubes arranged in the mica trough.

The practice as regards impregnating varies considerably. Wire impregnated before using is rarely employed; in most cases the whole stator is dipped and baked, but on large machines with open slots the practice is to impregnate and insulate the coils before placing them in the stator, and we have seen coils wound in position taken out to be insulated and impregnated, and then replaced. One firm tapes up the coils with a particularly coarse tape which has been previously treated with some bituminous compound. The result is a particularly porous

article, but one which lends itself to very thorough impregnation and varnishing.

The taping is done by females; it has been found quite practicable to have both men and women working together on big machines, the men winding and the women taping.

On the whole we are not favourably impressed by the insulation of the end connections of the stator winding, but the ample space which designers allow for their windings forms their factor of safety.

Forced ventilation of alternators is rapidly being adopted, and the axial cooling ducts already described are becoming almost universal in their use. The stator plates are invariably held by means of bolts arranged outside the magnetic circuit. Until recently makers did not make a standard line of medium-speed alternators for large outputs, slow-speed machines for coupling to slow-speed steam or gas engines (slow speeds being general practice among German engine makers), and high-speed machines for coupling to water and steam turbines being the rule.

It is interesting to note that the exciters are specially designed, and for direct-coupled units are fitted with an abnormally large number of poles for their output. Compounding of alternators is carried out by all firms even on medium-sized units.

Turbo-generators.—We are, unfortunately, unable to give weights and design data of turbo-generators, since their popularity is of but recent origin, so shall confine ourselves to the general features of design and workmanship.

Turbo-alternators.—No stator cases are made split on the horizontal centre line now, and, further, all large units are so arranged that the hot air from the stator is not delivered into the engine house, but is driven outside the building. Stator plates are held together by bolts, and are arranged with axial ventilation ducts. The winding of the stator coils is done by hand by most makers, the only formers for winding the end connections being the supporting clamps themselves.

The winding is otherwise the same as on slow-speed alternators, except that we did not see female labour employed here.

There are several interesting types of rotor construction, each firm has its own design.

Rotor by Firm A.—The rotor is cylindrical with a distributed winding. The hub or core is one solid forging with the shaft, to which the teeth are attached as follows. The teeth are built up of stampings in packets of about 6 in. length, so arranged that there is a clear space through from top to bottom on the middle 2 in. The packets are riveted together, and after being ground to size the rivet heads project about ¼ in. outside the packet, so that when the packets are placed together on the core a vent space of about ½ in. is formed.

The excitation coils are former wound and while subjected to pressure each coil is enclosed in a metal casing which is soldered up, thus rendering the coils watertight (*i.e.* non-hygroscopic) and affording excellent mechanical protection. The coils are laid on the core and

the teeth packets slid into position on either side of the coils. These teeth slide in grooves milled out along the core, the grooves being deep enough to permit a current of air to pass under the teeth to the vent spaces. The coil ends are bound down to the core body by means of banding wire wound on by a special machine under tension. Over the first banding comes a bronze sleeve and another banding on top of that. Copper wedges are driven over the windings in the slots and steel wedges are arranged in the empty slots to take up lateral pressure. These wedges when driven in press down the coils into the core with a pressure greater than the maximum pull due to centrifugal force, and they also press the teeth packets against the grooves in the core so as to form good magnetic contact. The bronze sleeve short circuits the copper wedges which form amortisseurs.

Rotor by Firm B.—The core of this rotor is built up of steel plates with the slots already punched in. These slots are unequal in width and unequally spaced, the spacing being so arranged as to give the desired flux distribution curve without having any empty slots. In cases of large outputs the whole rotor is forged out of the solid and the slots milled out. In this case the slot is very deep, with a shoulder half-way down on which a metal lining rests to support the winding. The lower half of the slot thus forms an air channel directly under the winding. The coils are wound on the rotor, each coil being separated from the following one by aluminium packing pieces. Press-spahn slot insulation is used, and the coil in one slot is wound in layers, the layers being kept separate by a special compound put on hot. In addition to the aluminium packing there are L-shaped steel plates, the lower limb of the L fitting in grooves turned in the rotor hub. The interstices are all fitted with compound and a bronze ring is shrunk on over all.

Rotor by Firm C.—This firm adopt salient-pole rotors from 4-pole upwards. They are usually built up of steel slabs (forged) approximately 3 in. thick, with forged steel pole-piece slabs dovetailed into the hub. The windings are of copper strip wound on edge and insulated with press-spahn. Bronze angle pieces hold the ends of the winding, and V-shaped packing pieces hold the coils in place laterally. The ventilation is through holes drilled in the slabs.

All rotors are dynamically balanced at a speed of about 50 per cent. above normal.

Exciters are specially designed, and in almost every case their armatures are carried by the extension of the rotor shaft without there being any additional bearings.

Steel slip-rings shrunk on over mica are used in conjunction with one carbon and two copper brushes to each ring. Standard practice is to arrange one ring at each end.

Turbo-generators for Direct Current.—There is much less demand for this type of machine, and the principle variations from English practice which we observed are in the ventilation of the armature. Here again the axial ducts are used, as many as three rows being

arranged concentrically. Field frames are usually built up of stampings.

To avoid the use of very long commutators these are now made in two halves and connected together.

Scientific Experimental Work in Factories.

Referring to the development of engineering since 1872 when Germany began her career as a great power, one finds that time and time again the Germans have taken up some design of an English engineer, and after a thorough investigation have devised important improvements. It is this thorough system of scientific investigation and experimental work that has enabled German firms to attain otherwise inaccessible eminence in certain branches.

There are several striking examples of this, perhaps the best known is the experimental high-speed railway, near Berlin, between Marienfeld and Zossen, which has been fully described in the technical press. Another example, well known to Members of the Institute, is the important series of investigations carried out on mining motors, a series with far-reaching results.

Less well known is the important test of the effect of heat and age on insulating materials carried out by one of the large firms. Samples of all kinds of insulation were kept at a constant temperature of nearly 100° C. for one year, some being kept under pressure. This experiment was of the utmost value to the firm concerned, but no results have yet been made public.

A considerable amount of plant has been laid down for experimental and special testing purposes, among the most recent being a water brake of 8,000 H.P. for testing steamship turbines at one works, and a wireless telegraph station at another works.

As an example of the application of scientific methods to works practice may be cited the dynamic balancing of all rotors and armatures of high or extra high peripheral speeds, as well as of all large size rotating parts while in the building-up stage.

Of course capital is required for these experiments, but as the German engineers are so well trained theoretically, and the German firms willing to employ them, the capital is rarely expended without some tangible profit. It is due also to these experiments that they are able to cope with special circumstances, and are also able to train the experts referred to in the earlier portion of the paper.

They have proved to the satisfaction of their financial supporters that money spent on careful experiments in the hands of capable well-trained men is capital well invested, and we would like here to insert a plea for the further recognition and better payment of the specialist in our own country.

Conclusion.—We have carefully avoided mentioning as far as possible anything relating to the other important branches of the electrical industry in Germany, since a separate paper could be easily written on

the management, manufacture, and design in each individual branch. The majority of our general remarks, however, apply equally well to other branches, viz., switchgear, instruments, lamp and cable manufacture. It has been attempted in this paper to give a brief survey of the German industry in the manufacture of dynamo electric machinery with the idea of investigating the factors of German makers' success, both in the German and the open market. Summarised briefly, we have, first of all, their commercial enterprise, including good general management, close study given to any scheme or undertaking, and the judging of each one on its own merits; secondly, their large capital and the backing up given them financially by the all-important banks. The large capital at their disposal assists them in their own country, and obtains for them good credit in foreign markets.

Coming to the manufacturing side of the industry, we consider the two-shift system, together with cheap labour, and the thorough system of specialising the most important factors in competition. In design England is in no way behind, in fact in several cases the English designers are more far-seeing, and their designs more practical than those of their German competitors.

If the English financiers and commercial leaders of the electrical industry were as enterprising and as successful as their German rivals, English manufacturers supported as they are by the superiority of their productions, would not have to fear German competition in the open market.

Discussion.

Mr. Garcke.

Mr. E. Garcke: So far as I am able to judge, the comparison which the authors make between electrical manufactures in Germany and England is well founded. The paper is particularly interesting in showing how the authors view the hidden economic factors of the situation. As they rightly say, "the financial development of the German electrical industry presents many features of interest and importance," but their conclusions in regard to the financial and commercial aspects of the industry in Germany and England are apparently formed without cognisance of all the facts and circumstances. A paragraph in the paper which deserves to be emphasised is the one commencing with the statement that "Almost all German firms insist upon the acceptance of their own specifications, and will rarely, if ever, depart from these." The statements, however, to which I wish particularly to address myself are those contained in the concluding paragraph of the paper, as I do not think they should be allowed to appear in the *Journal* of the Institution without some criticism. The paragraph itself is somewhat ambiguous, but the only inference I can draw from it is that we have nothing to fear from German competition provided English financiers and commercial leaders in the electrical industry do their duty. This view of the situation is not, in my opinion, justified, and should not, I venture to say, have been expressed without producing the evidence on which it is based.

I unhesitatingly say that the commercial men in this country, when not held back by restrictive legislation or by that "chaos of prejudices" known as public opinion, are the most forward in the world. In regard to our particular industry, we are certainly ahead, and well ahead, in the enterprise and energy of our commercial men and in the economy and efficiency with which we operate our undertakings, and the cost of production of our manufactures compares well with that of other countries; but we are behind, and sadly behind, in the profits we make and in the organisation of our industry. It is surprising how much misfortune we endure before we bring ourselves to adopt remedial measures, and meanwhile we accuse any one who ventures to point out the need for reform as being unpatriotic and as being actuated by selfish and unworthy motives. Undoubtedly our chief trouble is that, despite our lower costs of production, we cannot, under existing legislative and fiscal conditions, make sufficient profits to enable us to compete with manufacturers enjoying protected home markets. The importation of foreign manufactures is, as the authors show, very large, but the competition with German firms cannot be measured merely by our exports and imports of electrical apparatus. The imports would be much larger than they are if they had not already had the effect of reducing our prices to such a level that it is no longer very remunerative to the foreigner to sell his goods to us. Obviously our manufacturers cannot permanently subsist without profits, and should they have to give up the struggle, the foreign manufacturers would then have the English market on their own terms. We have brought our costs of production down to a minimum, but prices have been reduced in a larger ratio, so that the margin has practically disappeared. I am not speaking of any particular firm or company, but generally of employers of labour in this country. Now I wonder on what evidence the authors have come to the conclusion that we can by any kind of financial methods or commercial enterprise increase our profits under existing conditions? If manufacturers do not make sufficient profits to cover even their standing charges they are unable to push business, they cannot experiment with new things, and they cannot go in for publicity enterprise, neither can they send efficient travellers to foreign countries, and as we cannot offer capital a fair reward we cannot make extensions. I have been instrumental during the past twenty-five years in raising 15 or 16 millions of capital for this industry, and probably very much more as a fugleman. Shareholders will not be satisfied to be told that their capital has been used to produce "an industrial mascot, comely though poor, but very willing to work for and bring prosperity to others." Capitalists belong to a race which, being still human, cannot be expected to continue the practice of such altruism. It is quite unnecessary to demonstrate here that our profits are inadequate, the figures are published periodically, and are common knowledge. The reasons are numerous and complex, and I cannot attempt in a short statement to give even an outline, but they are to

Mr. Garcke.

Mr. Garcke. be found in the legislative, financial, and fiscal conditions under which the industry has been nurtured. Many of the difficulties under which we are labouring can be ameliorated, but to do so we must organise our forces. The reason why we are not organised is mainly because this Institution—which possesses the heart, the nerves, and the brains of the industry—has allowed its sinews to assume a condition of atrophy. We have relied too much on the efficacy of scientific discussion, while this Institution has considered it derogatory to undertake those active duties which are necessary in order to secure beneficent legislation and vigorous and healthy development. I do not know who is to blame—I am willing to bear my share. Let us remember, however, that it is not because the inexperience and inaction of industrial infancy may be condoned that the responsibilities of industrial maturity may be ignored. Let us look at the present position as we find it. Above all, we have an Institution which we all recognise as doing the most valuable and important work on behalf of scientific research, but an Institution which no one would venture to approach in any legislative or industrial difficulty. Then we have a number of sectional societies and associations which are doing excellent work in their respective spheres and with their limited means, but we have no organisation that can undertake the co-ordination of their separate efforts, and we have no organisation that can or will speak with full authority on behalf of the whole of the industry on legislative, financial, and industrial questions. I do not suggest that this Institution should descend from its high scientific level, but I do urge that it should abandon the erroneous belief that the scientific interests of the electrical industry can be best advanced by an attitude of apathy towards the commercial aspects. Our President has exceptional acquaintance with the remarkable organisations for the protection and promotion of electrical interests in Germany, and he is familiar with the important work they have done for the development and prosperity of the industry in that country. He must know how very deficient in these respects we are in this country. May I appeal to him, as I have done in vain to some of his predecessors, that he should give this question his earnest and serious attention during his period of office. I will give you only one recent example of the disabilities under which we are suffering by reason of the absence of an adequate organisation, but I could mention many others if there were time. When the Electric Lighting Act of this year was passing through Parliament it was brought to our notice that certain clauses were proposed to be inserted in the Bill which, if they had become law, would, I most unhesitatingly state, have put an end to further investment of capital in the electric supply undertakings in the provinces. A few of us approached the Board of Trade and canvassed Members of Parliament, and by dint of great efforts we succeeded in obtaining amendments. Similar steps were taken by some of the sectional societies in regard to clauses of the Bill affecting their interests. Surely it was exceedingly unwise to allow an Act of Parliament such as this to become law without some repre-

sentative organisation giving the matter efficient attention. There is a difficulty looming ahead of us which will require our most serious consideration. Whether we like it or not, the fiscal system of this country will sooner or later come under review. Are we going to allow this to be done without taking any part in the settlement of the question, or are we content to leave the matter to be settled by legislators who probably know nothing whatever of our requirements? Can it be a matter of indifference to this Institution as to what may become of the industry in such an economic whirlpool? Is not scientific research, for which we are all solicitous, largely dependent upon our industrial prosperity? Is it wise to attempt to divorce the commercial and technical sides of our industry? The two branches are inseparably united—the one cannot prosper without the other—and if the one is neglected the other undergoes decline. Without profits we cannot create fresh capital, and without new capital no new enterprises can be undertaken. Without capital and without profits we cannot do experimental and pioneer work, and if we do not develop we discourage our inventors and we transfer to other countries the technical initiative which, when stimulated by legitimate hope of reward in the form of renown or profit, is the foundation of all scientific progress. Mr. Garcke.

The PRESIDENT: I am not going to make a speech. I only wish to remind you that we are not a political body, but a body of technical men and scientists; and I warn you against the danger of bringing politics into our proceedings. We have before us an intensely technical paper, although it is financial as well. I did not stop Mr. Garcke, because it was not immediately obvious that his conclusions would be political, but I would appeal to subsequent speakers to keep politics out of our discussion. The President.

Dr. SILVANUS P. THOMPSON: This paper, sir, has given us, I venture to think, a very useful birds'-eye view of the progress of technical manufacture in certain lines in the electrical industry in Berlin. I am not quite sure upon what duration of experience the authors speak. No doubt they have seen things with their own eyes, but it would require a very lengthened experience, a residence of some years in Germany, to be absolutely sure that all the things that one might put down as being novel to one's own eyes were really novel in the place where they were seen. My impression is that that would be true of any country. A foreigner coming over to this country from the Continent or America, and looking round even for a few months, might be struck with certain things that he would think were new. But we who know them should not think them to be new at all. They have been growing up for years amongst us, and we should not regard them as a piece of modern progress. I am inclined to think, although I do not want to be hard in any criticism, that some of the things suggested as being recent developments in Germany are only the recent aspect of something that has been going on for a long time and has been the growth of years. You, sir, were for so long resident Dr Silvanus Thompson.

Dr Silvanus Thompson.

in Germany that there are certain detailed points upon which one would like some time or other to have your opinion. There has been a great deal going on, no doubt, in Germany, Switzerland, the United States, and other countries also in the way of improvements in detail, improvements in organisation, and improvements of various sorts, which we do not notice at the time; until something, possibly years afterwards, brings them to our attention, and then we say, "Oh, here is an important development!" It is in the natural order of things that we do not all at once see an improvement growing up, or recognise its tendencies. But it is useful, at any rate, to have the results of such things brought before us in a careful and thoughtful way, with due comment also upon the underlying questions of scientific and technical preparation, and also of the industrial conditions. I am inclined to agree with the authors that there is a good deal more importance to be attached than many of us have ever thought of to the question of the eighteen hours' day with two shifts. It must make an enormous difference to a manufacturer if, when he is full up with work, he can employ his machinery for eighteen hours out of the twenty-four and not have to pay overtime. That must be an enormous advantage. Then we know, again, that industrial conditions vary in different parts of even the same country, and I do not think it would be quite fair to say that the statements made in the paper represent Germany *en bloc*. What may be perfectly true in Berlin may be quite wrong in Munich, and may be quite wrong in what we should all for commercial purposes still regard as Germany, Bohemia, or may be quite wrong in Aix la Chapelle. It does not follow because a thing happens somewhere in one country that the same conditions obtain all over the country. I doubt if the conditions are the same in Westphalia as they are in Dresden. We in our own country can see that. We know that the industrial conditions are not the same in London as they are in the Midlands, or in Lancashire, or on the Clyde; otherwise why should we in London be complaining that there are practically no engineering works left, and that in twenty years London has ceased to be an engineering centre? Why? There are no tariffs to drive trade out of London and into Glasgow, or out of London into Birmingham, or Rugby, or Stafford. Trade will fluctuate, industrial conditions fluctuate—it is obvious that it is so. We must not take the condition in some one place and say that is the condition *en bloc* without knowing what it is in other places around. I fear that we may draw incorrect conclusions from perfectly correctly stated facts if we do not recognise that what is perfectly true in one particular place may not be true in another particular place in a more extended area. I made a remark some years ago—I forget exactly my phraseology—that manufactures always are more or less of a reflex of the surroundings under which they are produced, and cannot well be otherwise. Some twenty years ago, I think, I read a paper at the Society of Arts on arc lamps, and I then drew attention to the contrast in manufacture between the Continental arc lamps that were coming

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in from France, Belgium, and Germany, the arc lamps that were coming in from the United States, and the arc lamps that were being made by English manufacturers. I said—and I was criticised at the time—that the German, French, and Swiss lamps looked as though they were made by clockmakers; that the American lamps looked as though they were made by sewing-machine makers, and that the English lamps looked as though they were made by engineers. The genius of the place impresses itself upon the character of the manufacture. One cannot help it. It is bound to be so. I have often wondered how it is that no electrical manufactory has started in the town of Coventry, the very place one would have thought; because they have had in the town of Coventry various manufactures from time to time, including watchmaking, which for other reasons has gone away, so that we now have watchmaking in Prescot, in Lancashire, where it was not before, and watchmaking has gone from Coventry, where it was. Is it not obvious that tariffs have had nothing to do whatever with driving work from Coventry to Prescot, or from London to Loughborough? They are under the same conditions exactly, but there are environments that we may not be able to take into account which would, if we knew them, account for this shifting of industry. Some years ago there was a meeting held in this room *à propos* of what was then almost an unknown and certainly an unmanufactured thing in this country, a thing I was advocating to people who would hardly pay any attention to it, namely, the introduction of 3-phase induction motors. The suggestion was derided. It was said they would not work unless the clearance between the stator and the rotor was reduced to something like 1 mm.; and that it required, as Mr. Esson remarked, a nation of clockmakers and watchmakers to produce such a machine. Three-phase motors were certainly first produced satisfactorily in Switzerland, but they have come to England, and we can now turn out 3-phase motors just as good as those of any other country, and, according to the statistics of the authors, something like 10 per cent. better for the money. We have had to grow our manufacture, and to grow it in the teeth of the opposition of the industrial and commercial men who ought to have welcomed the progress of science. My memory goes back to the year 1898, when, at the Engineering Section of the British Association meeting, held at Bristol, I read a paper on "Progress in the Design of Electrical Machinery," pointing out how we were still filling our electric light stations with rows of little bipolar machines, every one with a little high-speed engine on the end of it, and that in other countries slow-speed multipolar machines of large diameter were being developed, and were being found to be superior. I advocated also 3-phase induction motors, and I advocated various other things in which we ought to have been making progress and apparently were not. I was answered by the chief partner of one of the largest and oldest established electrical manufacturers of this country to the following effect:—

"Oh, Professor Thompson need not suppose we do not know

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all about these things. We have been into them. We have our friends in Germany, who send us their designs and we send them ours. We have been into the matter, and it is a question of cost. It does not pay to produce multipolar machines; bipolars are better for the work, and cheaper. It does not pay to use 3-phase; it is much better to stick to continuous current; and it is quite evident that Professor Thompson is not a practical man."

Another argument used against what I had been saying, was that no practical man would dream of using electricity for any intermittent purpose. My reply was, "Intermittent purpose? I will give you an illustration from the very smallest and very largest. When you put the bells in your house you do not put up old pull bells; you always put up electric bells; and you do not go on ringing them the whole day long. When you want to put up a piece of heavy machinery, namely, a travelling crane that will lift up a great dead weight, you put up an electric crane nowadays"—and practically nothing else has been going up since 1898—"and you do not wind up your crane continuously all the day long: it is only used intermittently." The expression that was made use of then, that no engineer would dream of using electricity for any intermittent purpose, that multipolar machines were no good, and that polyphase machines were no good, came as an absolute damper against the paper of the poor individual who stood up in the British Association and said, "Here are lines of progress, and I want you to know about them"; and the very person who opposed it was a leading commercial engineer. I have occasion to plant students out in various places, and I know a little of what goes on in the employment of those students. I know that our own students who have been trained for three or four years, partly in the works and partly in the college, who have to calculate out and solve problems, have to work for next to nothing, for less than the pay of a common labourer, after having been trained. I asked one of these students, "Cannot you persuade the manager of your department to give you something better, because you are doing work that no common labourer can possibly do—calculating out the necessary amounts of wire for this, that, and the other; calculating out the right number of turns; calculating out the proper resistance? The firm could not get on without you or some one else to do this calculation, and yet they are paying you less than a labourer." The student to whom I gave that advice went and saw the manager of his department, who was very kind to him, and said, "Allow me to send for the sheets and show them to you." He said, "Look here. Here is the pay-sheet of men who are doing the winding and of the men who are doing the packing, but that is all *productive* labour. *Yours is only unproductive labour!*"

Mr. Raworth.

Mr. J. S. RAWORTH: I have very much satisfaction in addressing this meeting to-night under your Presidency, sir, because the bases of the discussion are known by you, and if any of us make mistakes in matters of fact you will be able to put us right. When I commenced to read this paper I was slightly prejudiced against it, because I began

Mr. Raworth.

at the back end. I read the conclusion, and I do not agree with that conclusion. It reads : "If the English financiers and commercial leaders of the electrical industry were as enterprising and as successful as their German rivals, English manufacturers, supported as they are by the superiority of their productions, would not have to fear German competition in the open market." I will just tell you a few words about "enterprising." You know that I am fairly intimate with Germany—that I passed seven of my best years in association with my friends, the Siemens Brothers Company, in which connection I was on friendly terms with many of those mighty men who made the great name of Siemens Brothers and the great "industry" of Siemens Brothers, the success of which stimulated the formation of the Allgemeine Company.

Going back to the early days (in the eighties), I was then associated in the Brush Company with Mr. Garcke, whom you have accused, sir, of making a political speech, although I do not know how we can touch this subject without getting on to politics, because in these days the wages we pay our workmen, and the provision that we make for their old age or disablement are matters of politics. I, for my part, observe with satisfaction, as the authors have shown us, that the legislature in Germany has taken great care of the working man, and if I may be allowed to say so, that it has also taken considerable care of the capitalist. I was going back to the days of the early eighties when I was associated with Mr. Garcke. What did we do then ? We went into Germany, and we lighted up the first public place in Berlin with arc lamps. When I tell my friends in Germany that we did that, they say, "Where was the Allgemeine ?" I reply, "I do not know, but I know where we were. We were in Berlin lighting the streets of Berlin with electric lamps." We went further—we lighted up a big cotton mill in Berlin. We went further than that ; we went into Austria, and we lighted up the Grand Opera in Vienna with 1,260 incandescent lamps. We went further still. We went to Temesvar, in Hungary, and we lighted the whole of the town of Temesvar so successfully that the Imperial Continental Gas Association was thrown out completely and had to take their stuff away. I want to introduce you to-night to Mr. Cottam—now engineer to the Borough of Hampstead—who was the engineer of that installation. He spent many years in Temesvar ; in fact, until the whole town was supplied with electric light by 37 miles of cable. Ultimately we sold the business to the town. How are you going to accuse us of not being enterprising ? We were enterprising enough then ; and, I assure you, that if it had not been for adverse circumstances we should have given the Germans in their own country some very good samples of our enterprise. Why did not we do it ? Well, we had good gas at 1s. 9d. to 2s. 6d., and they had bad gas at 5s. to 7s. ; we had a tariff against us of something like 10 per cent., but there was no tariff against them. There you have it ; that is the whole business in a nutshell. From the first moment that they made up their minds to have that business they were sure to get it : nothing could prevent

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them. I know the conditions under which the German industry has been conducted; I know some of the principal men at the head of affairs (I used to know the technical men, but some are dispersed and some are dead), and I can tell you that they are everything that the authors have described. They have the highest intelligence; they have the greatest enterprise, and above and beyond all that, when they want money the banks provide it. Why? Because the position is exactly the reverse of what the authors have stated. The authors have given us the idea that the manufacturers work the business up and then organise the banks. The actual state of affairs is that the banks usually are the father and mother of these manufacturing companies; they give them money whenever money is wanted; they find them business when business is wanted, and they share in the profit. The other side, and a very important side of the picture is, that the difficulty of obtaining capital for new manufacturing businesses is greatly increased. Moreover, the bureaucratic system of management lends itself neither to the rapid advancement of intelligent young men, nor to manufacture of special devices for special purposes. But, on the other hand, the extreme economy with which they are able to work these great businesses in reproducing standard apparatus enables them to command the markets of the world. They can get in where we cannot get in. They have cheap labour, they have cheap brains, they have Protection; they can build up a big business, and they can cut our throats while we struggle to get small orders and do work which the authors of the paper admit is superior to the work usually done in Germany.

Mr. Swinton.

Mr. A. A. Campbell Swinton: I think that the Institution is to be congratulated on its first commercial paper. I do not think we have ever had a commercial paper before, and this is essentially a commercial paper, and as such it appeals to my commercial mind. I was rather struck by a remark that was made by our President last night. He stated—and I agree with him in one sense—that in electrical engineering we are not behind Germany or other countries. I think from a scientific point of view that is perfectly correct, but not from a commercial point of view. He gave us one particular instance as a reason why we are not behind other countries: he said we supply electricity at less price. I must confess I cannot follow his reasoning in regard to this. If we supply electricity at a less price than other people it merely means that we are foolish; it does not mean any supremacy. If we make electricity cheaper than other people that possibly might be a reason for congratulation; but there, I suppose it would be argued that this is due, in a great measure, to our cheaper coal. The real criterion to my mind is this: Do we make larger profits? In that connection I read in the paper, with reference to German electrical companies, "A glance at the latest report of one of these Investment Companies shows that no supply company in which they are interested pays less than 6 per cent. dividend." I happen myself to have recently become connected with a large English electrical investment company

—probably it is the largest company in this country that deals with the financing of electrical supply undertakings, and this statement makes my mouth water, because no concern in which we are interested pays even 6 per cent. Now what are the reasons for this miserable state of affairs? To my mind they are several. One reason—a minor one perhaps—is connected with the Board of Trade Returns. How can you expect to do good business if you have to publish every detail of your costs? What private business of any description could prosper if it had to tell its competitors and customers exactly what it costs to make the commodity it supplies? I think these Board of Trade Returns ought to be suppressed. To my mind, however, much the most important factor—I hope I am not trenching on political lines—is that most insidious form of Socialism, municipal trading. We are suffering from not making sufficient profits. Apart from London, there are very few large electrical companies supplying electricity. There are a number of small ones, but there are but few in what can be called large towns. Now who sets the pace as regards the price at which electricity is supplied? The municipalities. The municipalities can borrow money comparatively cheaply, and the result is that they can supply electricity cheaply. That is very good for the consumer I quite admit, but it is not good for this industry. What this industry wants are profits, and we want to make the consumer pay as much as he will and can. What I am saying is not bad for the country as a whole at all. What is good for the country is that electricity should be produced as cheaply as possible, with as little waste as possible, and I think that all who have had acquaintance with municipal and company affairs will admit that companies are more economically managed than municipal undertakings. It is not only our supply undertakings that are not enabled to make good profits, but we cannot get any money with which to do anything electrical at all. We are accused of want of enterprise. I know numbers of electricians with plenty of enterprise, but what is the use of enterprise without money? It is stated that the financial people of this country are wanting in enterprise, and that they ought to find the money. But what makes the financial man find money? Profits, and if there are no profits nobody can blame him if he does not find the money. We always come back to the same point—what we want in order to make the electrical industry a success is to make profits. There are one or two very good instances in this country of how the finance of electrical supply, electrical manufactures, and other things are entwined together. In Germany the same company makes the machinery and provides the money to pay for it, and they are able to make profits in that way. As I said before, there are in England very few large places, except London—and I think London is in a category by itself and must be left out of account—where electric supply is undertaken by companies. All the large towns are supplied by the municipalities, and where this is the case the money is not ear-marked as an electrical investment. The capi-

Mr Swinton.

Mr. Swinton. talists who subscribe to municipal stocks do not know whether the money goes into electricity, gas, or drains; they get their interest and they do not trouble further about it. Take, however, the town of Newcastle-on-Tyne. Newcastle is one of the few large towns where electric supply has always been in priyate hands. The result has been that Newcastle had become an electrical centre; it has also become a place for obtaining finance for electrical schemes elsewhere. The people in Newcastle put their money into electric supply and found they got good dividends; and so they were ready to put their money into other electrical undertakings. The electrical supply undertakings both at Scarborough and at Cambridge were in the first instance almost entirely financed from Newcastle. Take another instance—quite a different one altogether—the town of Bristol. This is one of the few large towns where the electric tramways are in the hands of a company. The same result has followed. A large portion of the tramways in and round London and the tramways in Stockton and Middlesboro' were originally financed from Bristol. What I wish to point out is that what our electrical industry is wanting and is wasting for want of, is money; and the way to interest people in providing money is to give them good profits. If instead of the majority of the electric supply and tramway undertakings of this country being in municipal hands they had been left to private enterprise, the local people with money would have found them profitable undertakings, would have looked upon electricity as a profitable investment, and would have been ready to find plenty of money for new electrical enterprises and manufactures, and also for extensions of existing undertakings throughout the country. Municipal Socialism is thus condemned. It has been the curse and ruin of the electrical industry, which is the first new industry with which it has come in contact.

Mr. Mordey. Mr. W. M. Mordey: This paper is, I think, a valuable contribution to our knowledge of the industrial and engineering conditions in the two countries of Great Britain and Germany; but it does not lend itself very well to discussion except on some aspects of the subject that are not engineering aspects. I think we all know that profit-making is a very important branch of engineering, and we are glad that the authors have approached that side of the question in a spirit that is unobjectionable. Mr. Garcke has reminded us that some of our engineering applications in this country have not been profitable. That is unfortunately true, but I do not think that in most cases the fault is due to engineering at all. It is difficult to discuss these questions. One cannot help realising in these days that people's views on industrial questions very often largely depend on the political party to which they happen to belong. I agree with you, sir, that our only safe course is, as we always have done, to keep severely aloof from politics and to avoid all financial questions so far as they show any tendency to become political questions. With regard to the question of want of profits in certain parts of the industry—and it is very largely some of the manufacturing businesses that have done badly

Mr. Mordey.

—one cannot help feeling this is a question for commercial men rather than for engineers, and one might look at the industries that are successful for a guidance as to those that are not successful—compare, for example, cable-making and dynamo and engineering works. Or, look at another industry, for example, the iron industry, which on the whole is a very profitable one. When iron-makers find that the production is greater than the demand they reduce the production by blowing out some of their furnaces. In the electrical industry the capitalists have multiplied factories to such an extent that the available work is not enough for all of them, and they cannot make profits. They have defeated their own ends. I do not think that any one who knows the electrical industry to-day in this country at all intimately can say there is not an enormous amount of electrical manufacturing work being done—it is greater than it ever was. I happen to be and have been for many years advisor to people who are probably the principal makers of iron sheets and stampings of all sorts for dynamos, motors, transformers, and the like. They not only supply a large proportion of these things in this country, but they ship a good deal to Germany, America, and other countries; but I must not go into that because it leads into the question of protection. I visit these works periodically—I was there quite recently—and they are busier than they have ever been, producing more stampings of every sort and size for electrical machines than ever. There is no evidence whatever in their works of any depreciation or want of work in the electrical trade. I cannot help thinking this is at least a very good index of the amount of electrical machinery that is being made here, but, of course, it does not necessarily follow that that machinery is being sold at an adequate profit. To turn to another matter. Mr. Garcke has spoken of the new Electric Light Amendment Act, and blames this Institution for not taking any part in trying to get the provisions of that Act modified in the interests of the industry. In the first place, I would say that this Institution has never taken a narrow or one-sided view of its duties to its members and to the public. In considering the interests of members, we must do nothing that is contrary to the public interest—that in the broad sense is also the interest of the industry. The second thing I would say is that although the fact has not been advertised, this Institution did take an active part in connection with the recent legislation. A Committee of the Council had special charge of the matter—several meetings were held—a representation was made to the Board of Trade, and the Institution was asked to send a deputation to the Board to explain our views. I had the honour, as President, of attending as the nominal head of that deputation, which was well received. An important clause of the Bill dealing with a point of commercial interest was in fact modified in accord with the suggestions put forward by the Institution.

We are told that technical initiative is lacking in this country. I do not believe it at all. The greatest advances in modern engineering of recent years and of to-day have been and are being made in this

Mr. Mordey.

country, and are being copied by other countries. The most profound change in steam engineering is the work of an Englishman, Parsons; and quite recently we have a new and probably very important departure in the application of gas power to industrial purposes. I allude to Humphrey's remarkable application of direct gas pumping without the intermediation of any steam engine or motor at all. As to electrical supply, I have already done my part in trying to show the relation between the supply conditions of this country and the supply conditions in Germany. In electrochemistry we have very large and important applications. Then, as to the comparison between German and English practice, the authors have said that the German manufacturers dictate to their customers what they shall buy. That is true also of America—we, as engineers, do not believe that is a good policy. I remember in the very early days that a strong effort was made to standardise electrical machinery, and ever since there has been a movement to standardise things that were becoming obsolete. These efforts have not done much harm. In these matters, as an Institution, I feel that we should try and keep the balance between the efforts of different sections. I feel that the result attained has been excellent technically. It may not have been excellent commercially always. But what is the result? Electrical machinery made in Germany or in America would hardly be found to comply with strict British specifications such as we constantly observe without difficulty. At least that is my impression. A great deal has been said about getting money invested in our industries. I would suggest that the difficulty is principally in getting money for extensions of work which has not been successful.

Mr. Rich.

Mr. T. RICH: We are told that electrical engineers in this country are turning out cheaper and better machinery than that which is produced in other countries. The question at once arises, Why is it that in any great enterprise such as the Victoria Falls Company the Englishman has to stand aside? I think the answer is, that international competitions are decided by a sort of financial artillery duel before technical questions are considered at all. Unfortunately to-day the average English electrical company has to undertake competition with other people with practically no financial artillery; that is to say, they have nothing behind them beyond what they can raise on their bricks and mortar, and securities which are not already mortgaged. There is no financial institution, no body, in this country, which can say to big firms: "Go to South Africa, go to South America, and we will back you up." People blame traders and merchants and say, "Why is it that the German merchant in South America can give easy terms to his agents or to his branches? Why cannot the English firm do the same?" Consuls say exactly the same thing: "English firms are losing their business here, there, and everywhere because they will not give the same terms." That is not the fault of the English manufacturers. If they had the money in their pockets this end, or similar financial support, they could give as good terms as the Germans. At the present moment I think I am right

in saying the financial and industrial requirements of Chicago, Buenos Aires, Berlin, or Yokohama, are nearer to the London money market than English industry, especially the English electrical industry. I do not want to touch on politics, but the point I want to make is this—it is not due to the political arrangements of any party. It may be said that English industry in the last thirty years has had obstruction—some people call it regulation—which is unparalleled in any other country in the world. I have been on several occasions to the Continent, and people have said to me, "Why is it you do not have light railways running all over the country? Why don't you have overhead wires carrying high-tension current everywhere, as in France, Germany, and Switzerland?" My answer has been that there was an Act passed some time ago called the Light Railways Act, and since that date there has not been a single mile of genuine electric light railway built in this country, while there have been thousands of miles built on the Continent. It is only a few years ago that the authorities in Whitehall thought it possible to transmit high-tension current from one place to another through an overhead wire without dealing destruction in every direction, and yet the man in the street says electrical engineers are hopelessly out of date. When one visits Germany one is struck by the fact that it is essentially an industrial nation. When Bismarck started to build up that country he practically said, "This must be an industrial nation, and there must be strict co-operation between the legislature, the manufacturer, the financier, and the local authority," and during the last forty years they have had it. In this country, if a man wishes to build a light railway, it is the object of the local solicitor to work up opposition and earn fees. It is seemingly the object of the Board of Trade to say, "I wonder how expensively we can make this man build his railway, how many almost unnecessary safety appliances and regulations can we put in to multiply the capital cost by about three?" Then the public, when the whole thing has had to be abandoned, blames the engineer for want of enterprise! There is one more or less minor question in the paper to which I should like to refer. I see it is stated that the German electrical engineer is better theoretically educated than in this country. I beg very strongly to differ from that view. I should rather say that the average engineer in Germany has had possibly better opportunities for technical education than the student in this country, but I claim that he has not taken them. The average German student goes to a technical school, and for every hour he spends at a lecture he spends three or four hours outside the school in amusing himself. The average student leaves the technical school in Germany without knowing half as much of his business as the average student in this country. Here the students have to attend lectures, do their work, and go into the laboratories, and if they do not they have to leave the place. In Germany there is an immense mass of what I term semi-educated men who are suitable as automata and nothing else. The result is that we see from the paper that the technical men in Germany are exceedingly poorly paid.

Mr. Rich.

Mr. Clayton.

Mr. A. V. Clayton (*communicated*): I have had nearly ten years Continental experience in active electrical manufacturing, during which time I have myself been responsible for the establishment and conduct of large electrical manufacturing works on the German lines. I might mention that my Continental experience was not in Germany but in Sweden, where, however, the markets were practically monopolised by the German manufacturers, who were our keenest competitors, and hence we had naturally to study their methods and so be enabled to meet them on even ground. In our struggle with them we were quite successful and completely drove all German competition out of the country.

The help the banks give these Continental industries is enormous, and its worth cannot be over-estimated. Formerly a similar help was given to industries in England by local private banks; thus, for instance, it was the rule for woollen manufacturers to buy largely in the wool markets at the proper seasons, the bank allowing the manufacturer to overdraw his account very largely to pay for such purchases. This practice, however, even in these trades, seems to be dying out because the private local banks are by degrees being absorbed by the London banks, which conduct business on quite different principles. Not so long ago a leading man from the Yorkshire district pointed this fact out to me and stated that it is a growing belief among the Yorkshire manufacturers that a good opening exists in England for a properly conducted trades bank which would work on these lines. There is no reason why such financial assistance should be limited to textile industries alone. It is within my knowledge, and probably the knowledge of many, that the contracts for machinery supplies to many other large undertakings besides that of the Victoria Falls Power Scheme mentioned in the paper, have been secured to Continental manufacturers, purely on the basis of financial transactions. Another class of financial assistance largely made use of is called "Förlags Inteckning," and consists of an advance on the stock-in-trade of the manufacturer, in many cases loans being granted up to the full inventory value of the stock. Such loans are, of course, guaranteed by the directors, or the owner of the firm obtaining the loan, so that the stock-in-trade may not be sensibly diminished during the currency of the loan. It is apparent that where large machinery is manufactured which may require upwards of a year to go through the shops, such assistance is invaluable, as it allows the manufacturer the use of capital which would otherwise be lying dead in the shop. Further, most buying of materials is made on six months bills, cash payments being quite the exception, and the bank facilities for discounting such bills are very great.

Coming now to the next point in the paper, that of organising and specialising, there is no doubt that in a large measure specialising is the keynote of success in most German undertakings, but they sometimes go too far, and a little common sense and less red-tapeism would do a lot of good. An example will probably best show my point. It

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may happen that through an error in the draughting department the figures on a drawing do not check. For instance, if an error is made in the width of slot it may happen that all the teeth which should have existed are punched away; and I have known of a German shop manager, upon receipt of such a faulty drawing, to punch out all the material for the complete order strictly in specification with his drawing instead of pointing out the fault. Then when the punchings were assembled he sent in his official inquiry to know where the windings were to be placed. Any one who has worked in some of the large German organisations will no doubt have in mind many such instances, and it frequently happens that good relations are not maintained between the departments; dissensions, tale-carryings, and jealousies exist, which are very detrimental to the efficiency of the system as a whole.

As regards external organisation, I would like to emphasise the points put forward by the authors, and, indeed, Tables III. and IV. in their excellent paper are sufficiently striking in themselves. To this I would merely like to add an observation of my own experience. When I went to Sweden nearly ten years ago I found that many of the engineering shops there were fitted out with English-made machine tools. At the present time you will scarcely find any English machine tools in the shops in that country; they have been entirely superseded by German and American machine tools, and also tools manufactured in the country. The reason for the falling off of the use of English tools is to be found in the fact that English firms are very inefficiently represented in the country, and, moreover, the tools supplied by English merchants to Sweden have been of very antiquated type. The Swedish manufacturers have consequently got the impression that there are no good machine tools to be obtained in England. It may come as a surprise, but English tools are ridiculed by shop managers there. If a works manager wanted a lathe he was supplied by the English merchant (who probably knew nothing at all about the business) with an old-fashioned gap lathe having very weak bed, bearings, and spindle; probably the merchant was working off some antique stock which was unsaleable in England. The next time the factory manager wanted a lathe he ignored the English maker altogether, because he presumed that he had nothing better to sell, and this applies in an equal manner to the supplies of electrical plant. At one time a considerable number of English dynamos were sold to that country; this I am judging from old machines I have seen in different parts of the country. These dynamos were of continuous-current type for lighting, but when the real business of development by electrical transmission with 3-phase plant was begun there were no English 3-phase machines to be had, and as a consequence the trade fell to Germany. But even in the case of the continuous-current machinery the practice was exceedingly bad. Not so long ago I supplied railway motors from my own firm in Sweden to replace some English motors on an electric railway there. It will sound almost incredible when I tell you that the

Mr Clayton.

English so-called "*railway motors*" were old-fashioned, heavy, bipolar-type machines enclosed in tin boxes. At the date those English motors were supplied railway motors of the modern steel enclosing carcase type were being made in Germany and America. Is it therefore to be wondered at that in Scandinavia British electrical manufacturing is laughed at? Nobody takes it seriously. I notice that the authors state that the German manufacturers have not their own steel and iron foundries, but it will be found that the foundry firms co-operate with the electrical firms so as to give them practically the same advantages that would accrue from having their own foundries. The advantages I refer to, besides those of quick delivery, are principally in the way of patterns. That is to say, for the forming of large stators and yokes or articles which are not standard these are swept up in the sand without any patterns, whereby the heavy cost of the latter is saved. The boards used in sweeping up are of a very simple nature and cost practically nothing. I understand that English foundries will not undertake to carry out such work.

The two-shift day of eighteen hours is undoubtedly a great advantage where works are fully supplied with orders, though there are some drawbacks to it. Chiefly among these is the distribution of piecework. Suppose a piece of work is allowed a given price, the man working on the first shift does one part of the work on this job and the man coming on the second shift has to go on with it. When completed the piece price is divided between the men. Now, it is almost impossible to find men who will work satisfactorily in pairs in this manner. One of them will always be complaining that the other does not do his share, and in the event of faulty work each shirks the blame. On small work this can be obviated by allowing each shift its own individual work, but this is troublesome in organisation, and also complaints are made by the workmen that they lose time in the taking down and resetting up of the machine and the work on uncompleted jobs. Moreover, the disadvantages of having two men working alternately on the same machine tool will be apparent to all shop managers. A man who is working continually on the same tool gets to know it thoroughly, cares for it, turns out more work on it, and takes a pride in his machine which is lacking where the ownership of it has to be shared with another. In my own factories I have experience of two-shift working, but only to a limited extent in some departments, which were not able to keep up with the others, principally heavy machining and sheet-iron working, notching, etc. I tried to introduce it to the whole of the works, but, just as the authors anticipate, there was considerable opposition from the Trades Unions, and as we had just undergone a seven months' general strike I had to drop it. I may say that my reason for trying to introduce this system was to increase the already overloaded output capacity of the works whereby the necessity of building new works and consequent capital expenditure would have been avoided. As regards the rate of wages, I believe the extra productive power of the best English workmen compensates for any higher rate they

may obtain. In this respect I have probably a unique experience to relate in connection with the costs of machines produced in Sweden and in England, machines of identical designs and for which the same patterns are used. While the English workmen receive higher rates of wages, the actual cost of labour is lower for the English-made machines than for the Continental. This is especially noticeable in costs of windings, and, moreover, I am bound to admit that, as the authors have pointed out, the English workmanship is far superior to the Continental. Of course it will be said that this is not a comparison with the German labour, but from my experience, and from what I understand from others, the Swedish skilled labourer is admitted everywhere to be much superior to the German, and if we turn to the United States, to which a large number of them emigrate, we shall find that they are readily snapped up by the employers there. I do not think the authors have given sufficient weight to the "Kollonnen System." It is much more widely used than what one would be led to believe from the paper, and it is applied not merely to erecting, but also to machining and other parts of the work. It is certainly an excellent idea; it is like setting a thief to catch a thief, and certainly reduces costs and intensifies the rate of labour. Mr. Clayton.

Turning to weights of machines, I do not think the comparisons of weights given in Figs. 1 and 2 are of any value as a comparison. For instance, if one manufacturer is using cast steel for his yokes instead of cast iron, it would make a considerable difference to the total weight, and while the machine employing cast steel would be lighter, it might really be better and more costly. I have myself in the most modern designs of smaller continuous-current machines employed wrought-iron forgings for yokes, which, of course, gives extreme lightness. Comparisons on total weights of machines always reminds me of the case of an expert I once came across who decided the relative values of the machines of two manufacturers by taking their outside dimensions, the dimensions taken being height from floor to top of eye-bolt, length over shaft ends, and width over ends of slide rails. The manufacturer who had the longest slide rails and the highest eyebolt got the order! This was an acute case, but still I think all manufacturers have met the man who wants to get most weight for his money. For such customers iron yokes and heavy end-shields are necessary. Cast iron is, weight for weight, the cheapest part of the machine. The design data of the machines is much more interesting, but I notice in the case of the continuous-current machines that no data regarding weight of field copper are set out, and field copper constitutes one of the chief items of cost of materials. From the weights of armature iron given, one would be led to expect that the German manufacturers have very much less copper on their fields than the English; a point which I have noticed in some English machines the designs of which I have analysed, and perhaps the authors would tell us something about this. I think on alternators the Continental field copper is much less than the English. In two places I note that the

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authors have mentioned in a depreciatory manner the primitive formers and jigs used in German works, but I wonder if English manufacturers, at least some of them, do not carry the fetish of jigs and formers too far. One will frequently find that an enormous amount of money has been laid down in special jigs and tools, which may save a few shillings in the labour on a machine which sells at £50 or £60; but, on the other hand, if the designer can by better experience produce a machine in which the saving in materials, and possibly also in labour, would amount to several pounds per machine, the new design cannot be adopted by the manufacturer because it will not suit his special jigs and tools, which are too expensive to be scrapped. I dare say there are many managers, and possibly also shareholders, of works who would like to realise some of the money that has been uselessly sunk in special tools. In my own experience I have scrapped a complete standard line of machines from 5 H.P. up to 150 H.P. within a year of its design, because from experience gained during that time, and new ideas cropping up, it was found that cheaper machines could be produced by re-designing. Had special jigs and tools been made for all these machines such a revolution could not have been accomplished without enormous financial loss. Moreover, I believe in a greater flexibility of designs, and, in fact, it strikes Continental designers as ridiculous to see English continuous-current plant for slow speeds, say 200–300 revs. per minute, and of moderate sizes built out of 4-pole standard machines. The Continental designers would use about 10 or 14 poles, with a consequently better efficiency and cheaper machine. This is practically the same thing as the English makers sticking to the old bipolar machine when every one else had adopted multipolar design.

Under the heading of "Scientific Experimental Work in Factories" the authors have sounded another note in the right direction, upon which they should be congratulated. It is surprising to find the scrappy and unmethodical manner in which data are collected in English works, and unless English manufacturers, who have not already done so, will make total revisions of testing departments and departments for the collection of useful data for the use of themselves and their customers, they can never hope to compete with the Continental makers. It is exactly as the authors have pointed out, "If a screw was required the Germans are not content with being told the size of the screw, but want to see the place in which it is to fit." How often does it happen that English makers are required to quote, say on motors for intermittent work, and not having a scrap of information as to what their standard size motors will do in the way of overloads or temperature rises, they, in order to be on the safe side, quote a price for a machine which is really many times too big for the job. The Continental man comes, gets to know exactly what is required, has his complete filed tests and data on his standard machines, and can put in a motor which exactly does the work, and consequently at a much lower price. It is on technical points of this kind that the Germans

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are beating us every day all along the line, and the man who imagines that German manufacturers are dumping goods into this country—that is, selling them at a loss—is very greatly mistaken. They sell to make profits. Discrepancies in price on quotations between German and English makers can often be accounted for in the manner pointed out. Before concluding there are just two things I would like to point out in which I believe the Germans have a pull over us, and which the authors have not mentioned. One of these is that the German engineer is always thinking of his work even when he has left the workshop. In the evening over his beer and smoke he discusses the day's work with his companions, and thinks out for the morrow the best way of doing something. On the other hand, the young Englishman, even before he has put his coat on to leave shop or office, has forgotten all about his day's work, and devotes his spare time to studying football results or other such matters. As to which method is best for the nation in the long run I shall not discuss here, but as regards immediate benefit to the present generation no doubt the German is best. The second point is conscription. I have repeatedly seen men leave our works to do their term of military or naval service who have been laggards and more or less worthless men, but when they return on the expiration of their term of service they are quite a different type, they are disciplined and hard working, and seem to have a better outlook on the world. They realise the seriousness and responsibility of life, and know that there are higher laws commanding our existence and relations to one another than those formulated by themselves and their Trades Unions.

Professor Howe.

Professor G. W. O. Howe (*communicated*): Having had, some years ago, the privilege of spending two years in Berlin as an engineer with one of the four firms mentioned, I have read the paper with very great interest. It may be divided into two distinct parts, one giving a description of the machines made, and the other, of vastly greater importance, dealing with the designing, manufacture, and selling of the machines. I must confess that I see very little point in the comparison of weights, etc. With our modern facilities for transport, both of mind and matter, to say nothing of blue-prints, Berlin is little further from Stafford than is Manchester or Rugby. The slight differences that may exist between German and English designs are necessarily of minor importance. I was surprised to read that the taping is often slovenly. My ideas on the subject were quite otherwise, but such things have probably suffered in the price-cutting of the last few years. If the polish is not all that it might be, surely they are wise to economise in this direction rather than in something more essential. Such points are, however, mere trivialities. The undoubted fact remains that while there is little to choose between the manufactures of the two countries, the German firms are extending their trade at an enormous rate and paying large dividends, while English firms are struggling to make both ends meet and not always succeeding in this. In the face of this fact, it is useless to congratulate

Professor Howe.

ourselves, and to smile assent when our President assures us that "British shops can turn out work equally well and generally at a slightly lower prime cost." There appear to me to be several causes for this condition of the industry. In the first place, German engineering has only been able to compete with us by allying itself very closely to science. A German employer does not look askance at an applicant for employment because he pleads guilty to having had a university training; he welcomes him. We have improved much in this respect during the last few years, but there are still many employers who seem to prefer a "good practical man" with a mind unbiassed by scientific training. I was privileged to work for nearly a year in the experimental department of one of the Berlin works. Here were more than a dozen men engaged in research on a large scale. None of the ordinary dynamo testing was done in this department, but any machine which, on test, showed peculiarities, was immediately sent to this experimental department to be investigated, and a report on the matter would be sent to the designing department concerned. It is in such a laboratory that the single-phase traction motor, to take one example, can be gradually brought to perfection. The men for such work must obviously be specially selected for their scientific ability. German success is undoubtedly largely due to the enormous amount of post-graduate research work done, both in the colleges and in the works. The description of works organisation is very interesting. The eighteen-hour day with two shifts is, I suppose, a recent innovation. Can the authors say when this scheme was adopted by the leading firms? It would also be of interest to hear how they modify the scheme in times of slackness. In spite of the views so ably expressed by Mr. Garcke, I think that something must be radically wrong with the commercial and financial management of the leading firms of the English electrical industry. We expected that, as the result of the war in South Africa, there would be a great expansion of industry in that country. So far as the electrical industry is concerned, our expectations have been fully justified, but to appreciate it, it is necessary to turn to the German technical papers and read the annual reports of the leading German firms. When we remember that this is in a British colony, what can be more humiliating, and what chance do we stand in a foreign country? In South America, for instance, we are hopelessly outstripped, in spite of the equally good machine at a lower prime cost. Every electrical engineer will agree with Mr. Garcke that something must be done. It appears to me that the most pressing need is for co-operation between the leading firms in this country with a view to combined financial interests, on similar lines to the German industry-banks. Unfortunately, however, several of our leading firms are little more than English branches of Continental or American companies, and, so far as foreign competition is concerned, are working with their hands tied. Herein lies one of the weak points of our electrical industry.

DISCUSSION AT MANCHESTER, DECEMBER 4TH, 1909.

Mr. J. S. PECK: Perhaps the most valuable part of the paper is that which deals with the financial relations between the manufacturers and the banks or trust companies. Such an arrangement has undoubtedly proved of great benefit to the German manufacturing companies. Many contracts have been lost by British manufacturers to the German simply because the latter were able to assist customers in financing their undertakings. The tendency in this country has always been to buy in the cheapest market, whether from ally or competitor. Regarding the technical portion of the paper, it is extremely difficult to obtain accurate information as to the general practice of the different companies. All electrical manufacturing firms are changing their designs, their methods, and their systems from day to day, so that it is extremely difficult to obtain up-to-date information, and when one writes to the manufacturing concerns for data regarding their machines, they usually take into consideration the purpose for which it is to be used, and keep a supply ready for the purpose. Regarding the working day being divided into two shifts of 9 hours each, I understand that the A.E.G. Company are working three shifts of 8 hours each. It is stated on page 289 that individually the German workman is not so capable as the British workman. This appeared specially in the windings of high-voltage machines. A few weeks ago, I was inspecting the works of a large British manufacturing concern in company with the managing director of a large German Electrical Manufacturing Company, who was quite familiar with the general methods of manufacture in use in his own works. He criticised some of the British methods as being out of date, but was extremely complimentary regarding the quality of the workmanship. In some cases he said that the workmanship was too good. He seemed specially impressed with the fine appearance of the end windings on high-voltage machines, which was expressed in the words: "We can teach you nothing with regard to high-voltage windings." I should like to ask the authors what they mean when they speak of impregnated insulation. Does this mean impregnation *in vacuo*, and, if so, what materials are used for impregnating? On page 296 reference is made to a certain type of field winding for turbo-generators, in which the coils are wound longer than necessary, then cut through the middle, and the resulting U-shaped pieces put in from opposite sides, the connection from turn to turn being made simply by pressure between the straps. This is a construction which had been tried elsewhere and had not been found satisfactory, and I very much doubt whether it is standard practice in Germany. Mr. Peck.

Mr. M. GREGORY: On page 285 it is stated that the draughtsman is usually forbidden to enter the shops. This seems rather a peculiar procedure. Surely it is generally understood that a draughtsman should be cognisant of the general design of the machinery he is connected with, even should he specialise in one branch of the work only, as he Mr. Gregory.

Mr. Gregory. appears to do in these firms. It does not seem conducive to their interests to keep him away from the process of manufacture, and surely he should collaborate with his colleagues and the various heads of departments as to the best and cheapest methods of design for carrying out certain classes of work. With regard to the agents, unfortunately agents do not seem to be so fully conversant with the technical side of the subject as they might be, though one can hardly expect a man who has to deal commercially with clients to be thoroughly acquainted with all the necessary technical data, and it does not seem to pay an English firm to equip their agencies fully in this particular respect. On page 289 the author speaks of piecework on the "Kollonnen" system, where a sum of money and labourers' assistance are allotted to a man, and he has to erect a plant out of this sum. Does this apply to a case where, for instance, a whole lighting and power plant and electrification of the present steam-driven plant is to be installed? It is all right in the case where, say, a small amount of work can be put down in one unit; but where several unforeseen alterations are necessary to existing plant the man would be hopelessly at sea if a fixed sum were allotted to him with which to complete the work, unless it were out of all reasonable proportions.

Mr. Miller. Mr. T. L. MILLER: I think the two outstanding points in the paper are the description of the method by which the German electrical firms are financed, and the staffing of their branch houses in countries outside Europe. In my opinion, both these points have a very great influence with the manner in which the Continental firms have succeeded in obtaining many of the large contracts outside their own country when in competition with British manufacturers. With regard to the question of the staffing of their branch houses abroad, I pointed out in my address to this Section some three years ago how very necessary it was that if we wished to obtain our fair share of foreign work we should have good technical representatives on the spot. Most of the Continental firms, the authors have pointed out, have good technical staffs at their branches who are able to go into the whole matter on the spot, discuss designs, settle prices, and close the contract at once, and this puts them in a very strong position as compared with the type of representative which many of the British firms have in these parts. One fully appreciates the value of a good representative over in this country; a man who can come in and discuss the various details of design and manufacture, and their advantages over the manufactures of rival firms; but important as it is here, I am of opinion that it is of far greater importance when we come to deal with the foreign customer, and are brought up against the skilled representative of the German and American manufacturer. Then again, the backing given to the Continental firms by the banks enable them to take far greater risks than is possible for individual firms in this country to take, and this again gives the Continental manufacture a very great pull. A great point is frequently made of the superior technical education of the German engineer when dealing with this question of German

competition, but although we may have been somewhat behind with regard to technical education in the past, at the present time I believe we are fully able to hold our own, and I am strengthened in this opinion by the authors' remarks as to the design and construction of electrical machinery turned out by the two countries. The last speaker referred to the question of piecework on the "Kollonnen" system, and expressed the fear that this would not be applicable to work over here. I do not agree with this, and would draw attention to the fact that in comparatively recent times, at all events, it was usual in many shipbuilding yards for a leading hand to take a contract for the building of a vessel from the time the keel was laid until it was launched, they being responsible for the whole of the labour. If, therefore, this system can be adopted in work similar to that required in the building of the hull of a vessel, I see no reason why it should not be equally satisfactory in the erection of the much less complicated work mentioned by the authors. With regard to the draughtsman being forbidden to enter the shops, I cannot help saying that I think this is a great mistake. I think myself that not only ought a draughtsman to be kept in touch with carrying out the work in the shops, but he should also be required to give an estimate of the cost of carrying out the work in the shops, including the value of the material and the labour put upon it, but excluding profits, and that his estimate should be compared with the actual cost of carrying out the work, as it is only by so doing that the best results can be obtained. Mr. Miller.

One of the most interesting cases of methods of management I know of, where I think the question has probably received as much attention as at any other works in the country, is that of a well-known engine-building firm in the Midlands. In these works four committees have been formed from the members of the staff dealing with the design and construction of their manufactures. The committees are, I believe, a Designs Committee, a Works Committee, a Costs Committee, and a Sales Committee, each committee having on it some members who are on each of the others. The method of procedure in the event of a new design being brought out is, I believe, as follows: The design is first prepared in the drawing office and the complete design is submitted to the Designs Committee, where it is discussed and criticised by the members. From the Designs Committee it goes to the Works Committee, where it is discussed by the heads of the various departments of the works who deal more particularly with the method of manufacture. From thence it goes to the Costs Committee, where the question of cost is dealt with and an attempt is made to weigh whether the new design has any advantages as regards price, or whether the alteration is one likely to prove of benefit from the financial point of view. The design is then submitted to the Sales Committee, which is composed amongst others of the representatives of the firm, and who consider the matter from the customers' point of view and endeavour to find out whether the new design is one that is

Mr. Miller. likely to be taken up by the customer. By this means all departments have an opportunity of criticising a new departure before it is put on the market. Of course, where a large variety of different classes of work are dealt with, it may be difficult to adopt a system as elaborate as the one I have sketched, but even in such a case I think it is good policy for the heads of the various departments of the works to collaborate from time to time with those in the office and to discuss and criticise the designs before they go into the works. With a draughtsman kept in the office no doubt pretty designs may be obtained, but the most workmanlike and satisfactory results can only be obtained by the drawing office and the works working in conjunction the one with the other.

Mr. Frith. Mr. J. FRITH: I should like to hear more about the working arrangements between the four big firms mentioned. I have heard that it was more to the advantage of the manufacturer than of the purchaser. I would say rather that draughtsmen should be forbidden to stay in the drawing office than that they should be forbidden to go into the shops. Coming to the technical part, I should like to know whether, in the curves comparing English and German machines, allowance had been made for the fact that the German machines were allowed 80° F. rise, whilst the English would only rise, say, 70°, and also take a larger overload. If this had not been done the difference would be even more in favour of the English design. Also, is the commutator copper included in the weight of active copper? In the D^2l formula the n seems out of place, and the 10^{-4} would seem to indicate millimetres, not centimetres.

Mr. Faye-Hansen. Mr. K. M. FAYE-HANSEN: I have for several years worked as a foreigner in England and in Germany and may therefore perhaps be less biassed than most other speakers. I agree regarding many points, as, for instance, that the reason for the greater German success is not to be sought in better design or better workmanship, nor in the tariff conditions. It is stated at the beginning of the paper that practically only four large firms are of any importance in Germany at present. This may be true for the export trade of electrical machines, but there are quite a number of smaller firms having capital from £100,000 to £500,000 which are doing important work in generators and motors (in Germany itself) as well as in specialities. Works turning out turbo-generators and slow-speed dynamos of a couple of thousand kilowatts capacity are certainly taking part in heavy work. Regarding specialities, take, for instance, the Körting and Matthiesen Company; they are probably turning out as many arc lamps as any of the large firms. I think that the continued existence of many of the small firms is one of the reasons why the Trusts in Germany have not been detrimental to the German electrical trade, as competition in all classes of work has prevented the stagnation which otherwise probably would have taken place. Regarding the specialisation in the shops, this is, of course, now true regarding all large German firms, but I remember as recently as in 1902 the whole organisation of the A.E.G. works was divided into

three parts: electrical design including test, mechanical design, and production. The sub-division in departments according to the class of machinery is thus of very recent date. In the smaller firms, even in such a firm as Bergmann's, the sub-division is not carried out to such an extent as we are led to believe from the paper. Regarding the internal organisation, the authors have certainly either got wrong information, or generalised from some special works. For instance, it is not true that all engineers go through one of the drawing offices—there are many who start on the test-bed or directly in the electrical designing offices. Regarding contracts between the employers and engineers, they are practically on the same lines as here in England. The firms are, of course, safeguarding themselves against the employee taking advantage of tests and expenses incurred by them to take out personal patents, etc. But, as far as I am aware, the regulations four years ago were no more stringent in this respect than here. Regarding the draughtsmen not being allowed in the shops, I can only say that is not true regarding those firms I know of in Germany, which include two of the large firms mentioned. I should be very surprised if there is not some kind of misunderstanding, as the results obtained by the German manufacturing firms alone prove that such injurious (for the industry) regulations cannot be the normal ones prevailing. With reference to the working day, I certainly think this is a very important point. The working hours in the A.E.G. shops four years ago were from 6 a.m. to 2 p.m. and from 2 p.m to 10 p.m.—that is, 8-hour shifts with a quarter of an hour's rest. They got in a third 8-hour shift (night shift) to make the 24 hours complete when business was brisk or special short deliveries important. I think it is advantageous for the manufacturers to be able to work in such shifts. There is one further reason why it is more difficult for Englishmen to compete. I have noticed here several times that if rush jobs are going through the shops so that every one is behind them, the labour cost usually comes out less than standard, notwithstanding overtime rates, etc., which proves that the workmen ordinarily are not working up to their full capacity. I have not noticed the same in Germany, and believe that the Trades Unions' policy of restricting the output of each man is very injurious to the industry. Regarding wages, they certainly were four years ago higher than the figures mentioned in the paper. Most of the work is made in piecework, or on a bonus system, and for skilled workmen (skilled mechanics or tinsmiths) the weekly earnings were more in the neighbourhood of 50s. than 30s. On page 289 the authors state that German firms are not willing to deviate from their standard designs. Of course German manufacturers when pressed are quite as willing as any English firm to alter their standard if an important order can be thereby obtained. The German requirements, however, are very much more uniform owing to the existence of the recognised German Normalien, and also because relatively few independent consulting engineers exist. It is therefore comparatively seldom the German firms are pressed to deviate from

Mr. Faye-Hansen.

Mr. Faye-Hansen.

their standard practice. Here, however, especially the small consulting engineers have their petty wishes which they are able to push through. I believe that the absence of recognised Normalien and the existence of the different wishes expressed by nearly every consulting engineer, is increasing the manufacturing cost of the English electrical machinery all through by at least 5 per cent., as a larger technical and correspondence staff is required for the same output. I agree, of course, that the consulting engineers from many other points of view are of very much benefit to the industry, but purely from the manufacturing point of view they do more harm than good. It would certainly give a big impetus to the electrical industry if the consulting practice could be restricted to really eminent and broad-minded engineers. Regarding the "overland" central stations, one of the reasons why these have not developed in this country is the too great stringency of the Board of Trade rules regarding overhead lines. There is no doubt that at least in former years the German legislation and state regulations took the development of the electrical industry more into account than is the case in England.

Mr. Slacke.

Mr. R. B. SLACKE: I should like to know to what extent wages in Germany are less than they are in England, because some German works with which I am connected pay wages closely approximating to English prices. The average wage paid there per head is about 6d. an hour, including skilled and unskilled labour and apprentices. That is, I believe, just about the same average price as is paid in works of a similar nature in this country. It is not strictly electrical work, the firm being builders of large rolling-mill engines, etc., but I am comparing them with works of a similar class here. Their skilled erectors working out of the country get about 15s. per day, and English erectors, I believe, get about the same when working on the Continent. As regards the hours of shifts, it is very nice to be able to work 18 hours a day, but I very much doubt if many English works could have kept this up during the last two or three years, owing to slackness. As regards the question of branch offices *versus* agents, there is no doubt about it that branch offices ought to be very much more efficient. In many instances principals are very chary about giving full information to agents. Principals are also more inclined to keep their branch offices fully posted as to progress than their agents. It is for this reason not always an agent's fault if he is not as efficient as he might be, but, on the other hand, some firms are excellent in the way they keep their agents posted.

Mr. Wilson.

Mr. H. W. WILSON: My knowledge of German works is getting antiquated, because it is about seven years since I went through the whole of the principal German electrical works; but what struck me about the German works was the exceedingly good discipline that prevailed, and beyond that the comparatively small amount of work turned out per man. The men work exceedingly steadily, and I never saw a man that was not working, but he was never working very hard. They did a great deal of work in a long time. Of course, the hours of

work were somewhat greater than in this country, because at that time at the A.E.G. and Siemens-Halske works the workmen were supposed to put in, roughly, 60 hours per week, and the wages, as far as I could ascertain, were somewhere about 35s. per week, which is practically the same as is paid to the men in this country. Mr. Wilson.

Female labour in Germany seems to be more highly paid than in this country. In the winding department they got on the average something like 15 marks per week, and that is rather more than in this country, except in certain instances. Of course, there was a striking difference between German works and those in this country, in the design and supervision departments. At the A.E.G. works they reckon to have one skilled technical man to every ten workmen. The technical men were paid very badly considering their qualifications. Seeing the age of these men, and the amount of time they had to put in on their training, the remuneration was not very excessive; but there is no doubt the cost of supervision and design must be heavier than they are in this country as a general thing. The conclusion that I came to was that the German works could not be producing very much more cheaply than works in this country, if any cheaper, excepting on account of the fact that their output was very much larger, broadly speaking, and in consequence some of the establishment charges would be reduced. Owing to the double-shift system now worked the capital charges per item of output are bound to be lower. Where the German electrical manufacturing industry has its great advantage over this country is, however, in its financial backing. That is the whole secret of the matter. There is no doubt that if the English electrical industry could obtain the same financial backing that the German does it would be in a much stronger position than at the present time. The German works can command unlimited capital, speaking of things generally in the electrical industry, provided that they can show some reason for the expenditure they suggest making. The authors draw attention to the way in which large German firms carry out experimental work. Of course, these things are possible in America also, but absolutely impossible in this country under present conditions. I am of the opinion that the electrical manufacturing firms in this country will never make money with or without Tariff Reform unless the number of firms is reduced. There are too many people trying to make electrical machinery in this country. I was told some time ago there were 1,000 recognised makers of electric motors in this country; that, I should say, is about 975 too many. Although it is a very vexed question as to how electrical firms are to make a profit, I am of the opinion that the only solution lies in a very drastic reduction of the number of firms who are manufacturing, and an arrangement amongst them whereby they will be able to compete in foreign markets, not only from a financial point of view, but also in offering their products to possible customers. If a combination of firms in this country were to adopt the policy generally of sending out thoroughly qualified technical men who know the

Mr. Wilson. conditions and the language of the country, then there would be a chance of obtaining more of the large orders. The foreign representatives know their work thoroughly, and this is one of the principal reasons why the English firms are not getting anything like the export trade they ought to.

Dr. Bowman. Dr. F. H. BOWMAN: It appears to me that the superiority in Germany arises from three things: 1. That their Sales Department, especially in the Foreign Department, is better than our own. 2. That they have greater facilities in banking. 3. Certainly they work longer hours. With regard to the first, I think what has been said has already pretty well covered that ground. A great number of English firms do employ people as agents to represent them who know nothing about electrical machinery. No one can get on unless represented by people who know their business, and are able to give information to the parties who want it, and, knowing their requirements, can advise them. Then the banking facilities: there is no doubt in Germany they are far greater both in the engineering and electrical trades as compared with what they are here. Everybody knows that banks, where they will advance money to trading concerns, very frequently, if money gets tight, withdraw the facilities, and this is not done in Germany as much as in this country. There the bank frequently becomes a partner in the concern, and it is one reason why to-day German credit does not stand as high as English credit, because the bank assets are not as liquid as in this country. With regard to the workshops, I have been in many large German works. The first thing that struck me was the organisation, which is really better than our own. Instead of men hanging round as you see them in our own works, like a flock of sheep, when there is something to lift, they march up and take their position in military order; they all work together. The German works are, as a rule, kept much cleaner and tidier than our works are. In an ordinary English works you see screw keys in every corner, and piles of waste here and there. In the German works, in the power house, there is a glass case in which these keys are hung just like medals, just the same as in an instrument case, and the same order and system is seen in the shops. I had a high opinion of German works when I came away, and they can, if willing, do as good work as we can, but I saw work which would not have been passed in England, and when I complained about some of the winding I was told it was for export. The wages are very similar to what they are in England. Some of these men get 42 marks per week. That is a good wage, but they attend to six machines, that is, 7s. per machine. When I came back to England, I found we paid these men 28s. as against 42s. in Germany, but they are only allowed to look after two machines.

Mr. Cramp. Mr. W. CRAMP: The authors pointing to the dividend "earned" say that the state of the industry in Germany is satisfactory. I want to ask from whose point of view it is satisfactory? From the shareholders point of view certainly, but what about the purchasers, and the workmen? For although it may be reasonable for an ordinary manufac-

turing firm to pay a dividend upon its capital, I do not think 12 per cent. or 18 per cent. is reasonable from a purchaser's point of view, unless there is some very special reason why such a dividend should be paid. It seems to me that those dividends point to the existence of a sort of combination, which we in this country should try to avoid, especially when, as in this case, they do not go hand-in-hand with relatively higher wages. One speaker pointed out that there was a sufficient number of small competing firms in Germany to obviate the dangers of a trust or monopoly. I do not think that the figures quoted justify that view. On page 291 there are some curves given for the weights of English as against German machines. I have compared these with the statements made on the following page of the data, presumably for the same machines. I should like to emphasise what Mr. Frith has pointed out with regard to the formula involving $D^2 l\, n$ among these data, for I, too, can make nothing of it. The point, however, which I wish to make with respect to the curve, is that the ratios of total active iron divided by total active copper, and of armature iron divided by armature copper, which are given for English and for German practice respectively, are not such as would, in my opinion, lead to curves shaped like these. For if the above ratios be plotted against kilowatt, it will be found that the curves of English and German practice cross, and in some cases cross twice. My experience in design leads me to believe that the weight-curve will also take a somewhat similar form, and therefore I think that in considering that weight-curve there is some reason for believing that such parts as end-plates, etc., which do not affect the actual design, bear some important ratio to the final results, and that we ought to have data of the weights of *active material* rather than the *total* weight of the machines, if we are to form a fair opinion. There is also another point to which I would draw attention. The authors remark on page 293, with regard to induction motors, that there is a tendency abroad now to make the rotor longer and of smaller diameter. They say they think this is due to the frequent demand for high-speed machines. I do not think this is the explanation, for all the up-to-date English manufacturers are now making their rotors longer and of smaller diameter, because they find, especially for high-tension circuits, that the self-induction of the end windings is a very important factor. Better power factors can be obtained with the long rotor of small diameter, although the leakage must be greater across the slots from pole to pole. Leaving now the technical side of the paper, I may remark that various reasons have been suggested to-night to account for the fact that German firms can sell machines at prices apparently lower than the cost of making them here. The authors have in their concluding paragraphs suggested what I believe to be the correct reasons for this, where it exists. Now, it is said that it is difficult for us to export to Germany because of the tariff against machinery, and finished articles in general. Some few weeks ago I was at the works of the Morganite Company, London, who make carbon brushes, and the manager told me that if it had not been for the foreign demand for these brushes

Mr. Cramp.

Mr. Cramp. they would have been obliged to give up making them. He mentioned that of the carbon brushes they turned out, one million per annum were going to Germany to the very firms mentioned in this paper. On inquiring the reason why these firms placed their orders with the Morganite Company, I was told that it was because the full technical data which they provide of every quality of brush were much appreciated, and uniform results could be relied upon; the English manufacturer was too slow to take advantage of this, and so continued to buy his brushes abroad. As regards the cost of labour in Germany, Mr. Miller mentioned the use of "Kollonnen" systems in engineering shipbuilding particularly, and I have come across cases where the same thing has been applied in textile trades. Although it looks very satisfactory, from a manager's point of view, it is in my opinion a most insidious and dangerous practice, which leads very quickly to sweating of the worst kind. The employer himself very often has no knowledge either of the wages paid to the men or the large profits taken by the foremen.

Mr. Thomas. Mr. J. W. THOMAS: The rates of wages are about the same as in England, perhaps a little less, but the cost of living is also slightly less. It is the organisation of the large German companies which puts them on such a good footing. The authors do not mention over-production, but I consider this has done more than anything else in England to bring things down to their present bad state in the electrical business. The works with which I am connected are at present working three 8-hour shifts in the machine works. Very nearly all German electrical firms buy castings outside, and obtain a certain amount of business in return. I consider that the authors have generalised too much, and this makes their criticisms unjust in many instances. This applies particularly to finish of machines, as it is the high finish of the machines of the leading German electrical companies which is a special feature with them. There is much to be said for and against the banking system, but it must be remembered—and many seem to have forgotten the point—that if money is to be obtained from a bank it is necessary to put a sound scheme before them.

Mr. Adamson. Mr. D. ADAMSON: It has occurred to me during the reading and discussion of the paper that the Institution of Electrical Engineers would be well advised if it made a departure in the direction of one of the American Societies in the way of laying before the general public interesting or important information concerning developments of the branch of engineering the members were more particularly interested in. The authors mention that "English financiers and commercial leaders" are not as enterprising as those in Germany, with the result that financial assistance is more difficult to obtain. This difficulty I put down to the ignorance of the financiers of the possibilities of properly thought out electrical schemes. When it is found that other trades are more favoured financially than electrical engineering, I can only explain it by the fact that bankers are better informed

regarding such businesses as, for example, building cotton mills, for which there is no difficulty in raising money in certain parts of Lancashire, where the financial people are aware of the possibilities and also of the particular risks of this trade, and are prepared to advance the money. The history of electrical engineering in this country so far may, however, be said to justify the action of the financiers, because electrical engineering has never paid here, and the reason for this is, I believe, that prices in the early stages were not fixed sufficiently high to cover the risks which are incidental to all new developments, and when prices are once fixed at a low level they have a persistent tendency to remain so. If, however, the Institution of Electrical Engineers would, through some of its more responsible members, take the initiative in asking for the intelligent support of the public on the lines I have mentioned as already being considered in other countries, it would be to the advantage of the electrical engineers of this country. Mr. Adamson.

Mr. T. H. M. SWINBURNE: Referring to the paragraph preceding Table III. on page 286, so far as this country (England) is concerned, no doubt the authors are speaking from ignorance rather than from a desire to be misleading. There is no need before an audience such as this to detail the amount of care and investigation given to each scheme before a tender is sent in, and an agent of the "muddle-through-as-best-he-can" type is not usually entrusted with the work. Apart from all questions of financial backing and tariff, much of the success would seem due to the fact that whenever a German firm wishes to compete in this country, it invariably employs English engineers to exploit its interests in the first instance; then, when a connection is established, the Englishmen are replaced by Germans, and the usual results follow. Taking the case of other countries in the South of Europe, where English and German machinery are placed on the same basis as regards tariff, instances have arisen in which the preference has been given to English machinery, even if it costs 10 per cent. more than German, particularly so in the case of textile work. Referring to another paragraph on the same page, there is no doubt as to the Germans being willing to send in tenders; but any departure from the standard specification (referred to on page 289) invariably entails additional expense, and even then it is quite another matter as to whether the requirements are actually met. If tariffs be reformed in this country the results will doubtless be very different. Mr. Swinburne.

Mr. S. J. WATSON: I should like to have more information in regard to the financial arrangements made by the banks in order to find the money for the industrial concerns. What funds do the banks use, and do they accept as security the shares or mortgages on the industrial undertakings? This very intimate relationship between commercial undertakings and the banks does undoubtedly tend to help forward the carrying out of the schemes when the opportunity occurs, but it seems to me that during a time of great trade depression, trouble may occur. On page 286 the authors mention that some of these great commercial Mr. Watson

Mr. Watson.

undertakings hold exhibitions and lectures in different places, and that the engineer approaches the local mayor and officials and persuades them to put in a plant, and in this way many overland central stations have been erected. I should like to understand more clearly how the commercial undertakings can be financially interested in the work carried out for local authorities. It is a condition of affairs that cannot obtain in this country. One of the most important points in the paper is the double shift of workmen. Assuming a manufacturer in this country is turning out a certain quantity of work with a given amount of capital invested, if he adopts the German system he will be able to double the quantity of work turned out without investing another penny of capital. The proportion of capital charges to be put on the cost of each piece of apparatus will consequently be reduced to a half, and enable him appreciably to reduce the selling price. The question of scientific investigation which has also been raised is one which it is somewhat difficult to deal with. If a group of very rich undertakings is paying dividends of 18 per cent., it is no doubt an easy matter to set aside a certain portion of the profits for scientific investigations; but most of the manufacturers in this country are not in such a happy position, and when shares are standing very low because no dividends are being paid, you can hardly expect much assistance for scientific investigation. In his address last year, Mr. Miles Walker suggested that different institutions and associations might combine to form a school of investigation where different matters might be carefully inquired into; but so long as trade is bad and commercial undertakings in very low water, it seems to me very unlikely that the means will be forthcoming from these sources. On page 287 the authors refer to exports. I should like to know whether the value of the German exports to the British Colonies is included in the amounts given for Great Britain, or under the heading of other countries. One hears so much about the Germans ousting us from the market in South Africa and other Colonies that it would have been interesting to have had the figure for the Colonies shown separately.

Discussion at Birmingham, January 5, 1910.

Mr. Morcom.

Mr. R. K. Morcom: I would like to refer to the remarks made by Professor Kapp, the President, at the London meeting. Professor Kapp has warned us against the danger of dragging politics into our discussions, but I think it is very difficult to define any exact boundary. A careful reading of Clause 3 (B) of our Memorandum of Association shows how wide our powers are, and a perusal of back numbers of the *Journal* will show how widely the clause has been interpreted. One thing is certain, and that is that electrical engineering is influenced by other considerations than purely scientific ones. It would be of no use for a consulting engineer, for instance, to get out a 500-volt scheme if a grandmotherly Government chose to fix the limit at 30 volts, or for a designer to design a theoretically perfect machine which was too

Mr. Morcom.

expensive to use; in fact, in whatever branch of engineering we happen to be employed, we must sooner or later come down to sordid commercialism and undignified politics, and endeavour to see eye to eye with the manufacturer and the financier. In addition to such abstruse considerations as periodicity or forms of winding our discussions must take into account such matters as the ability of the staff and workmen, cost of raw materials, factory organisations, magnitude of the market, and the laws and regulations binding the individual, the factory, the supply company, the country itself, or even the fiscal conditions of that country. The price of the metal for a conductor is quite as important as its conductivity, and one of our greatest Presidents has formulated a rule correlating the two. I am sure that Professor Kapp would be the last to stop discussion on such points of finance or legislation, or even politics, as directly affect the prosperity and working of electrical manufactures or supply engineers. What the President's warning means is that we must not use the discussion of such a paper, as the one before us, as a grindstone for our own particular political axes, but confine our comments to elucidating points in the paper, or correcting any statements which may be misleading. With this understanding I feel sure we will all agree that it is best to keep to the President's ruling. Turning to the paper itself, I would like to refer to the German banks. They are larger than the banks in this country; but, then, there are fewer of them. The German banks are undoubtedly more speculative than the English; but there are two sides to that question. For instance, the collapse of the Dresden and Leipzig banks seriously upset the industry. However, the crash afforded the opportunity for merging the industry into a few large concerns, the prosperity of which is referred to on page 283 of the paper. I noticed in a balance-sheet of the Allgemeine Elektricitäts-Gesellschaft that the kilowatt output per workman was not so much as in this country, which probably means that the British workman is the more efficient man. The paper states that one great advantage of the large capital is the ability to meet sudden demands, such as that for special plant for the construction of large turbo-generators. But I have found when one is trying to get quotations for turbo-dynamos in this country there is no difficulty at all. The British firm will always give a quotation even if it has never made a turbo-generator before. The procedure in regard to the foreign department described in the paper is by no means rare in British factories, many firms having a special department not only for foreign trade as a whole, but also for each of the large countries in which they have agents. As for the authors' desire to encourage the growth of a larger body of technical experts in this country, salaries of experts are kept low in Germany. In a British drawing office one could not get anybody, let alone a chief designer, at the wages some chief designers get in Germany. The statement that English firms rarely trouble to send experts to investigate proposed schemes is really too sweeping. For instance, in different parts of the world my own firm has a number

Mr. Morcom.

of its best men whose sole work it is to go over different places where we have installations and examine them to see whether they are satisfactory. Every one of them can say "what screw is required and the place in which it should be fitted" as well as any German could. The paper states that the capital at the disposal of the German firms is an advantage in enabling them to lay down large numbers of special machines, thereby reducing the time taken in machining and the wages of machinists, and that German designers work with a view of adapting their designs to suit their machine tools. No doubt there is a good deal in this, but the authors cannot really mean that that sort of thing does not also prevail in this country as far as is advisable. In fact, in originality, organisation, economy, and equipment, an up-to-date British factory can hold its own against any one—the reasons for the poor financial results shown are no fault of engineers or manufacturers.

Mr. Orsettich.

Mr. R. ORSETTICH: As I have spent many years in Germany I venture to offer a few criticisms which I hope will be taken in the right spirit. It appears to me that the authors' observations are somewhat superficial. The explanation of the results obtained in Germany, and of the advantages which the German is said to have over the British manufacturer, seems to me not to be the real one. At the discussion of the paper in London and Manchester, whilst everybody commented on the fact that the banks in Germany are so strong, nobody tried to give an explanation of it. I believe that a great deal of the influence which the banks have had on the industrial system of Germany is due primarily to the law as to the constitution of public companies. In order to prevent undue competition and gambling, no shares of public companies can be issued for a less value than £50, and as a consequence of this there is hardly any public market for shares in Germany. The man who owns only a small capital cannot invest it in shares, but must put it in the Post Office or Industrial Banks. These banks are the repositories of the savings of the country, and whenever a manufacturer wishes to borrow money he goes to the bank instead of issuing shares to the general public in the way in which it is done in this country. This gives the bank the duty of supervising the investments in most of the German industrial companies. The banks become the centre of the German industrial world, and in the interests of their customers endeavour to ensure the companies being fully employed and to prevent competition among them. The German custom has a very good effect because the schemes promoted by any company have to be invested by the banking companies, who appoint either consulting engineers or financial investigators to prove whether a scheme is unsound, or whether there is any hope of a successful development. The investor, on the other hand, has a security that his own interests are safeguarded to a very great extent, so that he has very much more confidence in placing his capital in the bank for the exploitation of those particular works. This system of financing is also very advantageous to the new concern, because it does away with the heavy expense connected with company promotion in this country, and

Mr. Orsettich.

also with the tendency towards over-capitalisation which is always to be found wherever the promoters are not interested in the further working of the company. Another great difference between the constitution of industrial concerns in the two countries is to be found in the fact that the German companies are as a rule entirely public companies, whereas most of the English ones are really private concerns on a basis of limited liability. The effect of this is to be found in the amount of credit available for expanding or for undertaking new and risky lines of business. With our system it is always the credit of one or two owners, and therefore always a limited one, however rich they might be; in the other case it is the credit of one or more banking institutions with all their influence and connections. This fact in itself will easily explain the extensive development of the application of electricity in mines, iron and steel works, which took place in Germany, ahead of any other country. It was mentioned in the paper that the most important reason for the present success of the German electrical industry is their practice in regard to designing and their system of production. I do not see that these have very much bearing upon the conditions prevailing in this country at the present moment. It seems to me that the only cure for the present conditions is restriction of production and amalgamation of concerns. With regard to the large technical staffs employed I should like to touch again on the peculiar conditions of the country. Highly trained technical men are being turned out there at the rate of some three thousand a year, and naturally the price of the individual is low. This is very satisfactory from the point of view of the manufacturers, because they can keep a highly trained staff at a low expense, and use them for all sorts of secondary uses in the works. The number of uses to which a trained engineer is put in Germany is almost incredible. He is used for supervising small departments and in positions which in this country would be filled by ordinary clerks or workmen. The work is gone into more thoroughly, and a slow but continuous progress is achieved. Of course, whilst this is good for the industry, it is a very poor outlook for the men. The statement in the paper that all engineers pass through the drawing office is, I believe, incorrect. With regard to draughtsmen not being allowed in the shops, no doubt objections are made, as in England, to men wasting their time there; but it is no more difficult in Germany than in this country for a draughtsman to get a ticket to go into the shop. A great point is the systematic way in which things are done in Germany. Everything is dealt with in committees, and well thrashed out, while there is also an advantage in having the services of so many well-trained specialists. The management of industrial concerns being practically entirely in the hands of trained engineers, all matters are discussed and settled from an engineering rather than from a commercial point of view; the financial success is assumed to follow as a natural consequence of the satisfactory solution of the engineering problem. For the same reason a very broad-minded policy is observed in connection

Mr. Orsettich.

with experimental departments and laboratories for research work, on which very heavy sums are expended every year. One of the most striking features, and, in my opinion, one of the highest titles of merit of their policy, is to be found in the fact that during the crisis of 1901, whilst practically every firm reduced the expenses in all departments, no reduction was made in the staff and cost of scientific investigation.

Mr. Moffett.

Mr. F. J. MOFFETT: I consider that English manufacturing firms should take a leaf out of the German book and enter into working agreements "to prevent injurious competition," as is done by the amalgamated firms in Germany. The example has been set in this direction by the railway companies, the cable-makers, and to a certain extent by meter manufacturers, and the financial results have quite justified the adoption of such agreements. In connection with the electro-trustee banks, there seems scope for similar institutions in this country. I have been interested in a water-power scheme in Africa, the concession for which was obtained from the Portuguese Government, who guaranteed a sufficient payment for the public lighting of the streets, Government offices, and residences, to pay a minimum dividend of 5 per cent. on the capital necessary; but it was not found possible, in spite of repeated efforts, to induce any English manufacturing firm to finance the scheme. As regards the foreign departments, I was pleased to find, on a visit to Germany, that this, in the case of one of the largest firms, was almost entirely staffed by Englishmen. This goes to show that it is not English engineers who were at fault, but that it is financial backing that is required. The system which prevails in Germany of firms insisting on the acceptance of their own specification tends to make the manufacturers very arbitrary in their methods. When testing some plant for South America at one of the German works the hinges of the switches were found to be used for carrying current, in spite of the fact that it was specified that they were not to be so used, and great difficulty was experienced in getting this altered. In England manufacturers have the benefit of the researches and advice of the Engineering Standards Committee, which represents all sections of the industry, including purchaser's engineers as well as the makers. Consequently a broader view is taken as to the requirements.

Mr. Smith.

Mr. S. P. SMITH: The paper before us does not seem to me to be capable of being considered fair all-round criticism of German practice. I do not know whether the speculative system in regard to banks outlined in the paper could be adopted in this country, and it is questionable how such a system would stand adverse conditions. It is, however, rather a political question. One result of such untrammelled speculation, combined with the exclusion of adverse competition, is that the German firms can do to a certain extent what they like. For example, I believe it is a fact that when the German Government was recently considering a tax on electricity, the manufacturers asked their customers to withhold large orders with a view to influencing the Government. Another result of these arrangements between firms and banks is that the

Mr. Smith.

plants put down are often carried out on a far more elaborate scale than is the case in this country. When I was in Germany as a research student I was greatly struck with the number of technical men which they were turning out. Their lot, however, seems to be no better than ours, and there is little doubt but that they are rather overdoing it. Last year I received five or six letters from technical men in Germany, asking whether there was a chance of getting a start in England, as work and pay were so bad on the Continent. The average age of a man entering the works is much higher than in this country, and the pay is very poor; in fact, I rather think that the £6 5s. a month mentioned in the paper will be challenged, and that 80s. would be nearer the mark. I have even known £3 a month offered to men approaching their thirtieth year. With regard to English and German designing, I believe that, if anything, the English is superior, and that the English technical training is very hard to beat. The Germans have so little competition to fear that it does not matter whether their machines are all that is to be desired or not. The customer has to take what he gets.

Dr. Kapp.

Dr. G. KAPP: I confess that when I first heard the paper read and discussed I left in rather a despondent mood. There seemed to be a concurrence of opinion that we were really in a very bad way. But I now hear that things are not quite so bad. I have been privileged for many years to be interested in students, and I find that I now frequently get letters from old students abroad asking whether I cannot recommend them to some job in England, as they find it so hard to get anything in Germany. There is actually an over-production of scientific men in Germany, and although firms employ a greater proportion of black-coated workmen to workmen in overalls, yet there is not work for all. They have to work for very low wages, and if a man can get the £6 5s. a month, which the authors assert, he is lucky. A great many have to take a good deal less. In talking of the electrical industry we ought not to leave out the Swiss, as the people of that nation rank very high in skill. The scientific practical worker in Switzerland is a better man than his competitor in Germany. He also gets more wages and has to do more varied work. The German works in one particular groove because his employer gets more out of him in that groove. The condition of the technical man is really better in England, which fact is borne out by the presence of 10 per cent. of foreigners in this country. Another point raised by the authors was the three-shift system of eight hours each. I am rather astonished to hear of it, and it seems a new departure which had not been discovered at the time I was in Germany.

Messrs. Stelling and Lepine.

Messrs. STELLING and LEPINE (*in reply*): The last paragraph of the paper has been subjected to much criticism from various points of view, but we think the one taken by Mr. Rich in his remarks on the relations of financiers and manufacturers to be in line with what we had in mind when expressing ourselves in this paragraph. That manufacturers in this country do not receive the assistance of the

Messrs. Stelling and Lepine.

banks, as the German firms do, accounts for the loss of a number of large orders, which, there is no doubt, would be sufficient to fill up our shops and replace the present loss or meagre profit by a respectable profit. There is one point we should like to mention with regard to the raising of capital in which conditions are different in the two countries, and that is, in Germany the law is that no shares can be issued of less value than £50. This places a certain amount of restriction upon the small investor, so that we find that the chief investors in industrial and engineering concerns are the men with large capital at their disposal, or else the trading syndicates. It is these syndicates of large capitalists that take up electrical undertakings and make them pay. One of the syndicates mentioned in the paper holds shares in an immense variety of concerns, amongst which we find the names of firms carrying on the business of mechanical engineering, tramways in Russia, nitrogen works at Munich, and power supply at Victoria Falls. The lack of profits in English firms may certainly be due in some measure to restrictive legislation, but the Germans complain also of the same thing, and in turning up last year's reports we find the statement that restrictive legislation has reduced profits, but at the same time they have all managed to pay a higher dividend than in the preceding year. This seems to point to the fact that their foreign trade has been expanding, and we can only progress by giving the foreign and colonial trade our earnest attention. For instance, the A.E.G. have fourteen Europeans on their staff in China, one of whom is a director of the local bank. A failing of the English firms seems to be that they will not study local conditions. There is one phase, however, of the industry that is worthy of consideration, and that is if one looks at Germany, America, or Switzerland, one will find that the manufacturing firms there are essentially native. In Germany we know, for instance, that the A.E.G. was founded by American capital; Bergmann was also founded with American capital; but these firms have become essentially German in their nature in the course of time. In America there are nothing but Pan-American concerns, and in other countries in Europe it is exactly the same. But in England we have German manufacturing firms and we have American manufacturing firms, as well as our own English manufacturing firms. In no other countries in the world, we venture to say, have we such a heterogeneous collection of manufacturing firms as in England, and it is these foreign manufacturing concerns which are paying the lowest dividends, which are undercutting prices, and which cause the purely English industry to suffer. With regard to the point raised by Professor Thompson about the new things that we may have seen, it will be noticed that we do not emphasise anything because we have considered it new, but only where we know that the manufacturing process or design differs from average English practice. It is not necessary to make a long sojourn in a country to see whether manufacturers are doing things in the same way as ourselves, or in some other way. Our statements are based upon careful observations, and they were collected

Messrs. Stelling and Lepine.

with the idea of aiding an investigation into the reasons of the success of our German rivals. There is no doubt that the German technical colleges turn out as many semi-educated automata as do the English colleges; the one through their idea of leaving the student to his own devices, and the other through their system of "cramming." The essential difference between English and German training is that in England it is too often attempted to teach the practical side in the lecture theatre, whereas in Germany strict theory is adhered to with the idea of teaching the students to think, and courses containing general education are included in the curriculum. It should not be forgotten that proof of having attended lectures is necessary for the German student to pass his examinations.

We are not in a position to give any further details on the subject of working agreements. The important points are kept very secret, but perhaps the best known example is that of the cable ring. We would point out that we deal only with firms in the heavy electrical machinery trade, and in this line there are only the four firms mentioned who count. These are the only firms who pay dividends with anything like regularity, and are the only ones whose influence is felt in open competition outside Germany. We have therefore confined our criticisms and remarks to the methods and practices in vogue in these firms. We consider the Bergmann Company decidedly one of the large firms. The high dividend paid on the shares has the effect of obtaining good credit for the manufacturers.

We have not the space to give all details of the nature of German "Gemeinde" or communes and their system of government, but in reply to Mr. Watson we would briefly state that in many cases the communal rates are not sufficiently large to ensure the raising of all the capital required without crippling their activity in other directions. They can, however, take shares in the Company. Both banks and manufacturers take shares and the latter naturally supply the most economical plant for the purpose; they also ensure an efficient and economical running, while the banks look after the financial side. The money is borrowed on the security of the shares in the new company. Collaboration between departments is carried on very efficiently. In many cases letters are signed by two individuals, one representing the technical and one the commercial section. There are many reasons why draughtsmen do not usually enter the shops, such as distance of shops from office and consequent loss of time, specialisation of work and reluctance to let the men know too much of other departments, also the danger of men obtaining information which would be useful to other firms. Although it is not the starting-point, the majority of, if not all, young engineers pass through the drawing office. The conditions of drawing office work suggested by Mr. Miller are ideal and conducive to a very high efficiency, but the present state of the industry in England will hardly admit of their being adopted. Unfortunately English manufacturers have not been able to afford competent staffs, especially abroad, and have therefore

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been compelled to adopt as agents the "muddle-through" men whose existence certain speakers have questioned. We regret to state that we have distinct proofs of all our statements regarding agents and branch offices. Our statement regarding specifications of German firms is also supported by evidence in our possession. In a matter of agents we should like to cite an example of the system in vogue in Germany. Two South American young men of good connection came to a firm in Germany, passed through their shops, attended the courses at an engineering college, spent a year in the offices, and then returned to South America to their native towns as accredited agents. This method has been extensively and most successfully pursued by all the firms in question, and we venture to suggest its serious consideration by English manufacturers. We have nothing to add to our remarks on the question of wages, save that we have not given the rates with the bonus systems. There seems to have been a misunderstanding regarding the "Kollonnen" system. This applies, of course, only to the assembly in the works, exactly as in the machine-tool trade as we state. Impregnation is always done *in vacuo*, and varnish is used as standard practice. On some high-tension machines we have seen a very hard bituminous compound used in conjunction with very porous tape.

Our formula for the comparison of machines in which the letter n appears ($n =$ revs. per minute), gives what we believe to be a commercial value for the constant, but at the suggestion of Messrs. Frith and Cramp we have altered it to—

$$\frac{D^2 l}{\text{kilowatts at 1,000 r.p.m.}} \text{ for direct-current,}$$

and—

$$\frac{D^2 l}{\text{horse-power at 1,000 r.p.m.}} \text{ for alternating-current machines.}$$

English data ...	0·083	5 k.w.	English data ...	0·10	25 H.P.
	0·075	50 „		0·093	60 „
	0·085	150 „		0·080	150 „
German data ...	0·085	5 „	German data ...	0·088	25 „
	0·075	50 „		0·082	60 „
	0·080	150 „		0·072	150 „

It is obvious from the figures given that commutator copper is not included.

Our statement that "induction motors are being built with longer cores and smaller diameters, probably on account of the increased demand for high-speed machines," has been disputed. This opinion, we maintain, is correct. The value of the self-induction and power factor of induction motors depends upon the ratio $1 : \tau$ (core length to pole = pitch). It is therefore obvious that a motor whose average speed is represented by an average value of poles = 6, requires to be built with a longer core and smaller diameter than a motor with a slower average

Messrs. Stelling and Lepine.

speed whose number of poles is = 8, if we are to obtain the same power factor. Upon the pole-pitch depends, of course, the length of the end connections between the conductors. It is with the idea of comparing this tendency that we give values for $1 : \tau$ in our data tables. Our paper is written rather from a commercial point of view than a technical one; we therefore feel justified in giving complete weights of motors in the comparative curves, since these convey a better general impression of tendencies. These curves are for motors of continuous rating, such as would actually be supplied for standard work, and to the standard overload capacities and temperature rises of the respective manufacturers. No allowance is made for the varying overload capacities and temperature rises on the weights, for it is just this influence which gives a value to the curves.

While endorsing Mr. Morcom's remarks about the English firms quoting for plant they have not built, we may say that it will generally be found that the German firms are not only in a position to quote, but will be ready to show similar plants in operation. It seems that specialisation is carried to such an extent in Germany that a man is made into a machine. He is conversant only with his own work, and knows nothing of that of the man working next to him. In connection with subsidiary companies which are formed for dealing with foreign trade, they have a great advantage in that they take a name suitable to the country in which they happen to be, and also that they are able to deal in terms best understood by that country. Mr. Morcom has remarked on the advantages of having representatives abroad. While this may be possible for a firm of engine builders, it is not so in the electrical trade, which is not so well furnished with funds. But we would suggest that a good deal could be done if different firms could work together and combine to have a representative in places where it would not pay a single firm to support one. In important centres they could combine to keep a complete staff ready to design a power station and furnish complete schemes. German shops are more likely to be well looked after, if only for the reason that they are newer than English shops. The difference in regard to ventilation and setting out of the shops is very marked. It seems that the Germans adapt their designs better to suit their machines. With regard to the question of capital, Mr. Orsettich should be reminded that Mr. Stelling in the London discussion pointed out very clearly that the reason why the capitalist came in rather than the small investor was on account of the £50 share. As regards amalgamation, there does not seem at the present moment to be any group of financiers in this country who are prepared to buy up the whole of the electrical manufacturing firms, and this, I think, is the only way in which amalgamation will be found possible. The main reason why German machinery is coming into this country at figures so much below those at which the British maker can sell is the three-shift system, which enables them considerably to reduce their working expenses. The changing round of shifts is done at the week ends.

Messrs. Stelling and Lepine.

We gather that Mr. Smith does not consider the German commercial methods applicable to England, but apparently he does not appreciate that the difference of conditions is not an inherent or natural one, but is due solely to the disorganisation of the industry. The salary of 80s. per month is probably a good average for a man who has not graduated, but the figure given in the paper is confirmed as a fair figure for a graduate.

Proceedings of the Four Hundred and Ninety-ninth Ordinary General Meeting of the Institution of Electrical Engineers, held at the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, S.W., on Thursday evening, December 16, 1909—Dr. Gisbert Kapp, President, in the chair.

The minutes of the Ordinary General Meeting, held on Thursday, December, 9, 1909, were taken as read, and confirmed.

The following list of transfers was announced as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members :—

Walter Bridges. | Geo. R. Drummond.
Theodore A. Locke.

From the class of Associates to that of Associate Members :—

E. D. Bevenue-Miller. | R. H. Martin.
William A. Del Mar. | Charles N. Moberly.
Geo. G. Jobbins. | Hugh A. Pearson.
William E. Reath.

From the class of Students to that of Associate Members :—

Walter Riches. | James J. Roberts.
Frederick Swarbrick.

The following papers were read and discussed : "Some Quantitative Measurements in Connection with Radiotelegraphy," by Professor J. A. Fleming, M.A., D.Sc., F.R.S., Member (see page 344) ; and "Efficiency of Short-spark Methods of Generating Electrical Oscillations," by W. H. Eccles, D.Sc., and A. J. Makower., M.A., Associate Member (see page 387).

SOME QUANTITATIVE MEASUREMENTS IN CONNECTION WITH RADIOTELEGRAPHY.

By Professor J. A. FLEMING, M.A., D.Sc., F.R.S., Member.

(*Paper received November 2, and read in London on December 16, 1909.*)

The principles on which radiotelegraphic apparatus is constructed are now well understood, but the attention of designers and users is being more closely drawn to the consideration of the energy losses in various parts of it, and to the quantitative measurements necessary for a knowledge of the direction in which improvement is possible. The present paper is concerned with the means of making some of the measurements required.

The circuits in radiotelegraphic apparatus are for the most part inductive circuits in series or parallel with condensers, and whether the oscillations set up in them are free or forced, the important matter is to prevent dissipation of energy by resistance, brush and glow discharge, eddy currents, or dielectric losses of any kind due to conductivity or other causes. The first question, therefore, is the measurement of high-frequency resistance. We must, however, define precisely what is meant by this term.

High-frequency Resistance.—If a conductor has a cross-section of any shape, and distribution over it of current density z in any manner, then the high-frequency resistance of the circuit per unit of length (R′) may be defined as follows: Let $dx\,dy$ be any element of the cross-sectional area whose co-ordinates are x and y (see Fig. 1). Let the current density at that place be z and let ρ be the resistivity of the material, supposed uniform. Then $\int_{x_1}^{x_2}\int_{y_1}^{y_2} \rho\, z^2\, dx\, dy$ is the total heat generated per second in unit length of the conductor, and R′ is defined as the ratio—

$$R' = \frac{\int_{x_1}^{x_2}\int_{y_1}^{y_2} \rho\, z^2\, dx\, dy}{\left\{\int_{x_1}^{x_2}\int_{y_1}^{y_2} z\, dx\, dy\right\}^2} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

The total current through the conductor in $\int_{x_1}^{x_2}\int_{y_1}^{y_2} z\,dx\,dy$, and the resistance of the conductor varies with the change in the value of $\int_{x_1}^{x_2}\int_{y_1}^{y_2} \rho\, z^2\,dx\,dy$, subject to the condition that the total current remains constant. It is well known, and can easily be proved, that the resistance is a minimum for uniform current density over the

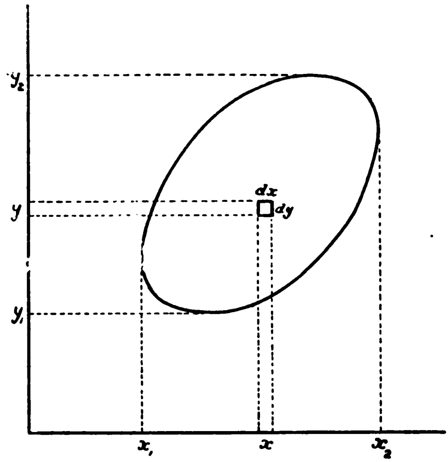

FIG. 1.

cross-section. The question can be treated as a problem in relative maxima and minima in the Calculus of Variations. It is clear that to find when the quantity $\int_{x_1}^{x_2}\int_{y_1}^{y_2} \rho\, z^2\,dx\,dy$ becomes a minimum subject to $\int_{x_1}^{x_2}\int_{y_1}^{y_2} z\,dx\,dy$ being constant, is the same thing as finding the condition of minimum of—

$$\int_{x_1}^{x_2}\int_{y_1}^{y_2} (\rho\, z^2 - C\, z)\,dx\,dy \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where C is some constant, and this by the known principles of the Calculus of Variations depends on the solution of a differential equation—

$$P - \frac{d\,P_1}{dx} - \frac{d\,P_2}{dy} = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

in which P stands for the partial differential coefficient of $\rho z^2 - C\,z = V$

with respect to z, and P_1 and P_2 for the partial differentials with respect to dz/dx and dz/dy respectively; the current density z being some unknown function of x and y.*

Since V here contains only z the equation (3) reduces to $\partial V/\partial z = 0$, or to $2\rho z = C = a$ constant.

In other words, the condition of minimum rate of production of heat for constant total current is that the current density must be uniform over the cross-section of the conductor.

This familiar fact can, however, be proved without the use of symbols at all.† It is not necessary to employ such a powerful implement as the Calculus of Variations on this simple problem. It is like using a steam hammer to crack a nut.

Suppose that the cross-section of the conductor is divided up into elements of area, and that each filamentary conductor into which we may suppose the whole conductor thus divided has the same resistance and carries the same fraction of the total current, as represented by the uniform shading in Fig. 2. Then we have equal current density.

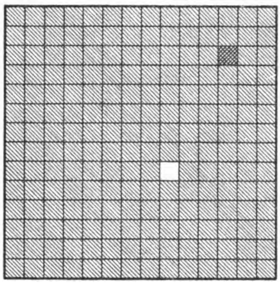

FIG. 2.

Imagine that the current is removed from one filament and added to that in another, as indicated by the white and dark small squares in Fig. 2. Then the total current is not altered, but the heat generated in the first-named filament becomes zero, and in the other four times what it was before. Accordingly the total heat generation is increased, although the total current is not altered. The resistance of the conductor as above defined is, therefore, increased by any change in the distribution of the current which makes its density non-uniform over the cross-section. Moreover, by this mode of viewing the phenomena it is easy to see that any distribution of current density which is non-symmetrical round the periphery of the conductor is also a cause of increased resistance as compared with that corresponding to a symmetrical distribution of current density. Accordingly, not

* See Todhunter's "Integral Calculus," chap. xv., p. 358, "The Calculus of Variations."

† See "An Elementary Manual of Radiotelegraphy and Radiotelephony," J. A. Fleming, p. 10.

only is the resistance of a straight, solid conductor greater for high-frequency oscillations than for continuous currents, but the resistance of a spiral or helix of wire for high-frequency currents is greater than that of the same wire when stretched out straight, because in the first case the current density is greater at the periphery of the wire than at the centre, and in the second case the peripheral distribution is non-uniform, owing to the fact that the external distribution of field is non-uniform, being greater on the interior parts of the solenoid than on the outside. Mathematical formulæ for the ratio of the high-frequency resistance of a solid straight conductor to its steady current resistance have been given by Maxwell,* Mr. Heaviside,† Lord Kelvin,‡ Lord Rayleigh,§ and Dr. Russell.||

Dr. Russell has given a general formula for the high-frequency resistance of a concentric main or two coaxial cylinders, and shown that the formulæ previously given are particular cases of his more general formula.

If we consider a circular-sectioned wire of non-magnetic material of resistivity ρ and of circumference c centimetres, where $c = \pi d$, d being the diameter, and suppose it traversed by a high-frequency current of frequency n, then, if n is of the order 10^6, we may put the expressions given for the ratio of the high-frequency resistance R$'$ to the steady current resistance R in the following form :—

Let $c^2 n/\rho = h$. If, then, h has a value greater than about 100, the formula applicable in the case of high frequency given by Lord Rayleigh is equivalent to—

$$\frac{R'}{R} = \frac{1}{2}\sqrt{h} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The more exact formula given by Dr. Russell for the same case is equivalent to—

$$\frac{R'}{R} = \frac{\sqrt{h}}{2} + \frac{1}{4} + \frac{3}{32\sqrt{h}} - \frac{1}{16h\sqrt{h}} \quad . \quad . \quad . \quad . \quad . \quad (5)$$

By plotting the formulæ given by Lord Kelvin and Lord Rayleigh (4) in terms of a common argument (h) the author had, previously to seeing Dr. Russell's formula (5), come to the conclusion that for values of $\sqrt{h}$ exceeding 5 or 10 the ratio of R$'$/R could be very well represented by the expression—

$$\frac{R'}{R} = \frac{\sqrt{h}}{2} + 0{\cdot}3 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

* See Maxwell, "Electricity and Magnetism," vol. ii., p. 690, 2nd edition.

† Oliver Heaviside, "Electrical Papers," vol. ii., p. 64.

‡ Lord Kelvin, Presidential Address, *Journal of the Institution of Electrical Engineers*, vol. 18, p. 4, 1889.

§ Lord Rayleigh, "On the Self-induction and Resistance of Straight Conductors," *Phil. Mag.*, vol. 21, p. 381, 1886; or "Scientific Papers," vol. ii., p. 486.

|| See Dr. A. Russell, *Proc. Phys. Soc.*, vol. 21, 1909. Also *Phil. Mag.*, vol. 17, p. 524, 1909.

which is seen to be very nearly equal to the first two terms of Dr. Russell's expression. We may therefore assume that for high frequencies a simple formula giving the ratio R′/R when the quantity $\sqrt{h}$ is greater than about 5 or 10 is :—

$$\frac{R'}{R} = \frac{1}{2}\sqrt{h} + \frac{1}{4} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

which is true for circular-sectioned non-magnetic wires. Thus let us take the case of a No. 14 S.W.G. copper wire subjected to oscillations of a frequency of $\frac{1}{2}$ 10^6. We have for this wire $c = 0{\cdot}635$ cm., $c^2 = 0{\cdot}403$, $\rho = 1600$, $n = 5 \times 10^5$, and hence $h = 125$, and $\frac{1}{2}\sqrt{h} = 5{\cdot}59$. Hence $R'/R = \frac{1}{2}\sqrt{h} + \frac{1}{4} = 5{\cdot}84$. Accordingly the resistance of this wire for the above frequency is nearly six times its steady resistance. For the same mean square value of continuous currents and alternating currents of frequency 5×10^5 the energy dissipation is therefore nearly six times greater for the high-frequency current.

We have hitherto had to rely entirely on this mathematical predetermination of the ratio R′/R for our estimate of the augmented energy waste due to high-frequency oscillations. It is important, however, if possible, to test these formulæ experimentally, and also to measure the ratio R′/R for cases such as coarsely stranded wires 7/20 or 19/18, for which no theoretical predeterminations have yet been made.

Apparatus for Measuring High-frequency Resistance.—The following apparatus has therefore been devised by the author for experimentally measuring the ratio of high-frequency resistance R′ to steady current resistance R. Two glass tubes T, each about 75 cms. long and 3 cms. in diameter, have an expansion at the upper end and a curved bend and expansion at the lower end (see Fig. 3). The ends are provided with indiarubber corks perforated by thick rods of copper and the lower bends are filled with mercury. The upper corks are also made airtight with mercury or oil. These tubes have side tubes blown on by means of which they are connected by an inverted syphon of barometer tube which contains coloured paraffin and an air bubble I in the centre to detect its displacement. This arrangement constitutes a differential air thermometer with two tubular bulbs. In these tubes are placed two identical wires W which are fastened to the copper rods passing through the corks at the upper ends and dip into the mercury in the bends at the lower ends. It is convenient to keep these wires in a truly axial position by one or two discs of thin mica. Suppose, then, that we pass the same electric current through these wires in series. Both are heated and heat the air in the tubes, but if everything is symmetrical and the tubes are equally heated the bubble is not displaced. To attain this balance, however, the whole apparatus has to be placed in an enclosure and the position of the bubble observed through a window. If, then, we pass electric oscillations through one wire and a steady current through the other it is possible to adjust the steady current until the heat produced by it in one wire balances

the heat produced by oscillations in the other wire. To do this the currents, measured by thermal ammeters A and A_1, have to be passed for some time so that the thermal condition may become constant. Assuming, however, that this is the case we have the following state of affairs: In one wire which has a resistance R we have a steady current A producing heat at a rate A^2R. In the other, wire of high-frequency resistance R' we have oscillations of root-mean-square value A_1 producing heat at a rate $A_1^2 R'$. Since the sources of loss are the same in both cases when the final steady thermal state is reached we have $A^2 R = A_1^2 R'$ or $R'/R = A^2/A_1^2$. The measurement of the root-mean-square value of the currents in both cases is conducted with similar

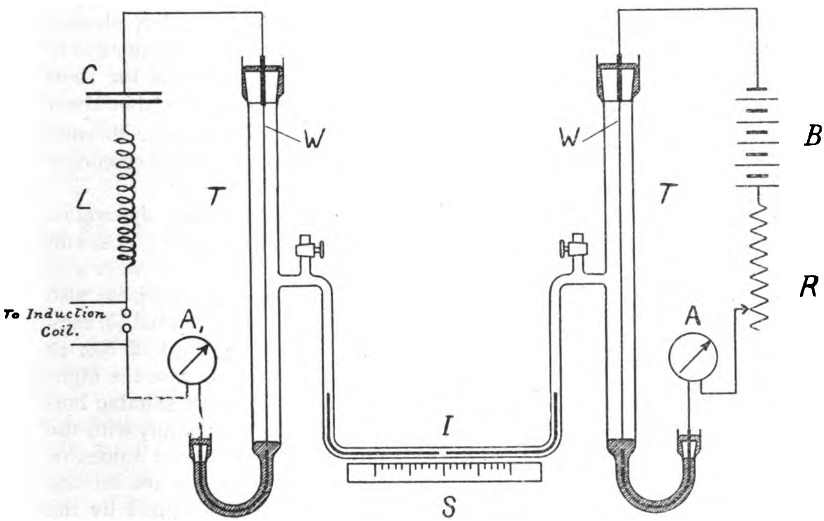

FIG. 3.—Differential Electric Thermometer for High-frequency Resistance Measurement.

hot-wire thermoelectric ammeters. These are made as described below (see Fig. 4).

To eliminate certain causes of error depending upon any inequality in the surface emissivity of the two wires it is necessary to adopt a process of double weighing similar to that introduced by the author in the case of electric lamp photometry in a paper read before this Institution in 1902,* which was found to give good results, and immediately adopted in the photometric department of the National Physical Laboratory and elsewhere. In this case instead of passing a steady current through one wire and the oscillations through the other, and

* See J. A. Fleming, "The Photometry of Electric Lamps," *Journal of the Institution of Electrical Engineers*, vol. 32, p. 144, 1902.

taking the ratio of the currents when the thermal balance is reached, we first balance the oscillatory current against a steady current and then substitute for the oscillations another steady current and balance again. Or, better still, we may simply reverse the connections and make two observations in which each wire in turn carries the oscillatory and the steady current. It is generally found most convenient to keep the value of the oscillatory current constant and to take the mean of the two readings of the continuous currents. Some precautions are necessary to obtain good results, but it will be seen that the process is a kind of Wheatstone's bridge measurement in which a balance is obtained between two rates of production of heat or two temperatures instead of between two potentials.

The apparatus was first tested with two No. 14 S.W.G. copper wires, each 60 cms. in length and equally clean. For this wire, which is 0·203 cm. in diameter, and for a frequency of half a million the ratio of R′/R is about 5·84 from theory and therefore the ratio of the root-mean-square values of the oscillatory and steady currents should be about in the ratio of $\sqrt{5{\cdot}84} : 1 = 2{\cdot}41 : 1$. That is to say, when the thermal balance is obtained the R.M.S. value of the oscillatory current should be $1/2{\cdot}4 = 0{\cdot}4166$ of the value of the steady current.

Tests were therefore made with the above-described apparatus, using in the first place a pair of No. 14 S.W.G. bare copper wires, and determining for them the above ratio experimentally. Tests were also made with No. 16 S.W.G. and No. 36 S.W.G. bare copper wires; also with stranded wires $\frac{2}{16}$ and $\frac{7}{22}$ bare copper and with stranded $\frac{19}{36}$, each strand insulated; also with copper strip and with a spiral of No. 16 copper wire and with a German silver wire. In each case the high-frequency and continuous currents were measured with suitable hot-wire ammeters, and the frequency determined experimentally with the cymometer. The results of observation and the measured values of the ratio R′/R are given in Table I., and against these are set the calculated values in the four cases of single wires obtained by the Russell or Kelvin formulæ. The value of $\sqrt{h}$ is also given when it can be calculated.

The same apparatus can be used for investigating the high-frequency resistance of spirals of wire, which, as already proved, is greater than that of the same wire stretched out straight. For this purpose we place in the tubes two similar spirals of wire, and compare the resistance to high frequency to steady currents. As is well known, this extra resistance due to spiralisation was brought to notice by F. Dolezalek,* and has been discussed theoretically by M. Wien,† and A. Sommerfeld,‡

* F. Dolezalek, "Uber Präzisionsnormale der Selbstinduktion," *Ann. der Phys.*, 1903, 12. 5. p. 1142; or *Science Abstracts*, 1904, vol. 7, B, Abstract 488.

† M. Wien, *Ann. der Phys.*, 1904, 14. 1. p. 1; or *Science Abstracts*, 1904, vol. 7, A, Abstract 2272.

‡ A. Sommerfeld, "Über das Wechselfeld und den Wechselstromwiderstand von Spulen und Rollen," *Ann. der Phys.*, 1904, 15. 4. p. 673; or *Science Abstracts*, 1905, vol. 8, A, Abstract 591.

and examined experimentally by T. B. Black,* A. Batelli, and L. Magri,† and more recently by L. Cohen,‡ and J. W. Nicholson.§

With regard to the extra resistance produced by spiralisation, it can hardly be said that the formulæ already given for predetermining it are satisfactory. The formula given by Sommerfeld is certainly not in agreement with the experimental results of Black. But Cohen claims that the formulæ given by him are in agreement with his own experiments. Black experimented with spirals made of wire respectively 0·15 cm. and 0·3 cm. in diameter, and with oscillation frequencies of 10^6 and 5×10^6 respectively. He found that the high-frequency resistance of these wires in the form of single-layer spirals was to that of the same wire stretched out straight in some ratio between 1·25 and 1·89 to unity for the above-mentioned frequencies.

Using the apparatus above described, two measurements were made with spirals of No. 16 copper wire, 0·16 cm. in diameter, formed into spirals 54 cms. long, 2 cms. in diameter, and having 2·6 turns per centimetre of length. The results recorded in Table I. show that for a frequency of about 450,000, the resistance of this spiral is to that of the same wire stretched out straight in the ratio of 1·25 to 1. Hence, even for such an open spiral the spiralisation may increase the high-frequency resistance 25 per cent. over that of the wire itself when straight. Again, the results obtained with the $\frac{19}{38}$ wires show that merely bunching or twisting silk-covered wires as fine as No. 36 S.W.G. is not sufficient to produce a conductor of which the high-frequency resistance is the same as the steady-current resistance.

The results of experiments made with $\frac{19}{38}$ wires spaced well out showed that the ratio R′/R is then reduced nearly to unity; but the conclusion to be drawn from these experiments is that to obtain a conductor the resistance of which to high-frequency currents is the same as its steady-current resistance, it is not only necessary to bunch or twist together fine silk-covered or insulated wires, but the strands must be so arranged that each wire is similarly situated with regard to the others and to external space, and this is not the case when they are stranded as usual. Also experiments show that No. 36 wire is not sufficiently fine for this purpose; No. 40 S.W.G. silk-covered wire should be used.

These experiments have also shown that it is not an easy matter to construct a thermal ammeter which correctly measures the R.M.S. value of large high-frequency currents, for this implies making a conductor for large currents in which the ratio $R'/R = 1$. It is essential that it should not be a shunt instrument. The whole current must

* T. B. Black, *Ann. der Phys.*, 1906, 19. 1. p. 157; or *Science Abstracts*, 1906, vol. 9, A, Abstract 572.

† A. Batelli and L. Magri, *Phil. Mag.*, 1903, Ser. 6, vol 5, p. 1; or *Science Abstracts*, 1904, vol. 7, A, Abstract 355.

‡ L. Cohen, *Bulletins of the Bureau of Standards*, Washington, No. 76, vol. 4, 1907–8. "On the Influence of Frequency on the Resistance and Inductance of Solenoidal Coils."

§ J. W. Nicholson on the "Effective Resistance and Inductance of a Helical Coil," *Proc. Phys. Soc., Lond.*, December, 1909.

therefore be carried by fine copper wires well spaced out, and their temperature is best ascertained by a thermoelectric junction made of fine wires, of iron and constantan, or iron and nickel, attached to one of them.

A suitable form of hot-wire ammeter for measuring large high-frequency currents is shown in Fig. 4, in which W are a number of bare No. 36 copper wires soldered to end-pieces of brass which are connected to main terminals T and T′. A thermoelectric junction J is attached to the middle wire and is connected to terminals T_1 and T_2, and by leads to a Paul single-pivot galvanometer. Such an ammeter can be calibrated by continuous currents, and will then give the R.M.S. value of a high-frequency current correctly.

The experiments prove, however, that in this differential electric thermometer we have an appliance which affords the means of finding experimentally the ratio R′/R for any wire, and that in those cases in

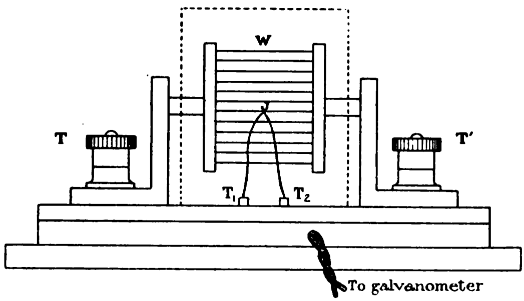

FIG. 4.—Thermoelectric Ammeter for Large High-frequency Current Measurement.

which we can compare the experimental values with those predicted by mathematical theory the two substantially agree. Hence we have confidence in the results of the measurement in those cases in which the ratio cannot be predetermined by theory. We are therefore now in a position to test the portions of any oscillatory circuit for high-frequency resistance, and when we can measure the mean-square value of the current in it by a hot-wire ammeter, we can predict the power dissipated in it as heat. Values obtained experimentally in this way for the high-frequency resistance of two No. 16 copper wires loosely twisted and for $\frac{7}{21}$ stranded tinned copper wire give numbers useful in predetermining the high-frequency resistance of antennæ.

Standards of Capacity.—The next matter to which reference may be made is the construction and measurement of standard capacities and inductances. Glass is the material commonly employed as the dielectric in condensers for practical radiotelegraphy, except in the case of large power stations where the use of air, either under normal or increased pressure, has many advantages. Glass as well as ebonite and mica are, however, quite unsuitable for making standard high-frequency con-

Calculated Value of the Ratio of the Resistances $\frac{R'}{R}$	Remarks.
5·92 7·60	Calculated by the first three terms of the Russell formula, taking ρ = 1,700
4·53 4·56	Calculated by the first three terms of the Russell formula, taking ρ = 1,700
1·02 1·07	Calculated value obtained by Lord Kelvin's formula
— —	— —
— —	— —
— —	— —
— —	— —
— —	Ratio of resistance of spiral to that of same wire stretched out straight for n = 450,000 = 1·25
1·20 1·21	Calculated value obtained by Lord Kelvin's formula, taking ρ = 26,600

densers on account of the variation with frequency of their dielectric constants. Even if air condensers are used for this purpose, there is always some uncertainty whether we are justified in concluding that low-frequency measurements of the capacity, of an air condenser give us the correct high-frequency capacity, on account of the spurious augmentation of capacity which is due to glow or brush discharges which occur at high voltages and frequencies.

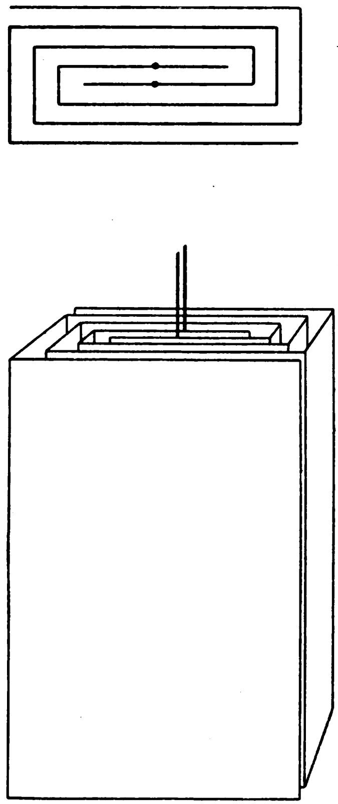

FIG. 5.—High-frequency Condenser.

Hence the author gives preference to condensers made with well desiccated paraffin oil as dielectric having metal plates immersed in it as follows :—

Two rectangular sheets of stout zinc are bent round formers into square-cornered spirals, the section and appearance of the sheets being then as shown in Fig. 5. The turns of the two sheets are intertwined so that the surfaces of one are opposed to those of the other.

These sheets are kept about 1 cm. apart everywhere by four ebonite strips having saw cuts in them, which are fitted on the zinc sheets at the top and bottom, and connecting wires are also soldered to both sheets. These sheets are placed in a sheet zinc box and immersed in high flash-point paraffin oil which has been treated for some days with fragments of metallic potassium or sodium to remove all moisture. The sheets must be insulated from the box by ebonite slips. The desiccated oil forms the dielectric. Such paraffin oil has a dielectric constant of about 2·0, tested at low frequencies, and since its optical index of refraction is close to 1·41, its dielectric constant for optical frequencies must be near 2·0, and hence we may conclude with some confidence that its dielectric constant has also the same value for frequencies of the order of one million or so. The low-frequency capacity may be determined at a frequency of 100 or 200 in the usual manner by charging and discharging the condenser through a calibrated galvanometer or by any of the bridge methods.

It is, however, necessary to measure the insulation resistance of the condenser, and to be extremely careful that the oil used is freed from every trace of water, or else no accurate capacity values can be obtained. The author has constructed a set of six such condensers, each having a capacity of about 0·0005 microfarad. These are conveniently placed in wooden trays, and can then be joined in series or parallel as required.

It is absolutely necessary for good results that the condensers should be enclosed in a metal box which is kept earthed. The capacity of the plates is the sum of their mutual capacity and also their individual capacity with respect to the earth or surrounding objects. Hence if the plates are contained in a glass or ebonite box the total capacity is affected by its position with regard to surrounding objects, and the only way to obtain constant capacity is to enclose the plates in an earthed metal box, from which, however, they are insulated by the same dielectric (oil) which separates them from one another.

The low-frequency capacity of these condensers was determined at a frequency of 100 by a rotating commutator, and the charge or discharge integrated by a galvanometer, and the values of each condenser obtained from the mean of a number of closely accordant measurements.

Having, then, provided a known standard of high-frequency capacity we can use it for the comparison of other glass condensers or Leyden jars used in making up transmitting apparatus. These measurements of small capacities can most easily be made by means of the cymometer, as already described by the author, when we are concerned with the values for high-frequency work.

Standards of Inductance.—To determine frequencies and therefore wave-lengths we must associate a known capacity with an inductance, the value of which can be predetermined exactly. No form of inductive circuit is so convenient for this purpose as a rectangle of wire. A wooden frame is constructed having a groove in the edge, and in this groove can be laid insulated copper wire, which is bound in place by

silk or string. The wire circuit is cut at the centre of one side and a pair of bullet-shaped spark balls inserted, which slide on the wire. The opposite side is cut to insert the condenser.

The dimensions of the rectangle of wire are then carefully measured. If A is the mean length of one side and B that of the other, and $D = \sqrt{A^2 + B^2}$ is the diagonal and d the diameter of the wire, then the high-frequency inductance L for peripheral distribution of current is given by the formula—

$$L = 9{\cdot}2104 \left\{ \overline{A + B} \log_{10} \frac{4AB}{d} - A \log_{10} \overline{A + D} - B \log_{10} \overline{B + D} - \frac{A + B - D}{1{\cdot}1513} \right\} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (8)$$

The proof of this formula (8) is long but is given in the author's book, "The Principles of Electric Wave Telegraphy," chap. ii.

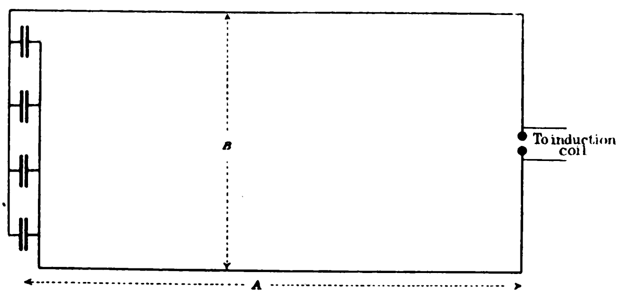

FIG. 6.—Arrangement of Condensers and Rectangular Circuit to form a Standard Oscillation Circuit.

It should be noticed that the formula given by Messrs. Rosa and Cohen in Bulletin No. 93, issued by the Bureau of Standards, Washington, U.S.A., in the valuable collection of formulæ and tables for the calculation of mutual and self-inductance, for the inductance of a rectangle, is based upon the assumption of uniform distribution of current over the cross-section of the wire, and therefore differs somewhat from that given by the author above. The Rosa-Cohen formula gives a value larger than that of the formula (8) by an amount equal to $A + B + d$.

Thus, if we construct a rectangle 2 metres long and 1 metre wide of No. 14 S.W.G. wire, $A = 200$, $B = 100$, $D = 224$, $d = 0{\cdot}2$, and $L = 7717$ cms. by the formula (8), but it is 8017 cms. by the uniform current density formula given in the Bulletin.

Standard Oscillation Circuits.—If such a rectangle is associated with a capacity of 0·001 microfarad it gives us therefore an oscillation circuit having an oscillation constant ($\sqrt{CL}$) equal to $\sqrt{7{\cdot}717} = 2{\cdot}778$ corresponding to a wave-length $195{\cdot}56 \times 2{\cdot}78 = 543$ ft., and if associated

with a capacity of 0·006 microfarad it corresponds to a wave-length 2·45 times greater, or 1,330 ft. Accordingly rectangles of no very cumbersome size associated with oil condensers of moderate capacity cover the range of frequency most required for wavemeter calibration.

The best method of uniting the rectangular circuit and the oil condensers to form a standard oscillation circuit is as shown in Fig. 6. One end of the rectangle is doubled on itself and the condensers inserted as shown in parallel. The discharge path for each condenser is then of the same length, and the mean length A of the rectangle is defined by the line half-way between the closely adjacent double wires or bus wires between which the condensers are placed in parallel.

When, however, we require standard oscillation circuits of lower frequency it is necessary to interpolate in the circuit some more compact form of inductance—such, for instance, as a spiral of one layer or a flat helix of known predeterminable inductance. The use of spirals involves, however, a small correction not only for the capacity from turn to turn but for the change of inductance produced by distribution of current. This last can be annulled to some extent by using fine stranded wire made up of twisted silk-covered No. 40 copper wires. The advantage, however, of using the rectangular inductance is that no capacity correction is required; and if spirals are employed it should be reduced as much as possible, keeping the turns of wire well separated by winding them in a screw groove cut in an ebonite or marble cylinder.

Inductance of Single-layer Solenoids.—It is necessary then to consider the predetermination of the inductance of single-layer spirals of various forms and types. Consider first single-layer spirals of insulated wire. Maxwell showed that the inductance of a circular conductor of n turns having a rectangular section of radial depth d and axial breadth b and mean radius r is approximately—

$$L = 4\pi r n^2 \left\{ \log_e \frac{8r}{B} - 2 \right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

where B is the geometric mean distance of the section from itself—that is, the geometric mean of the distances between all possible pairs of elements of area into which we can divide the total cross-section. The value of log B for a rectangle is—

$$\log B = \log \sqrt{b^2 + d^2} - \frac{1}{6}\frac{b^2}{d^2} \log \sqrt{1 + \frac{d^2}{b^2}} - \frac{1}{6}\frac{d^2}{b^2} \log \sqrt{1 + \frac{b^2}{d^2}}$$
$$+ \frac{2}{3}\frac{b}{d} \tan^{-1}\frac{d}{b} + \frac{2}{3}\frac{d}{b}\tan^{-1}\frac{b}{d} - \frac{25}{12} \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

It will be seen that the expression remains the same if b and d are interchanged. Accordingly for the same mean radius and turns a circular coil with rectangular section of breadth b and depth d has the same inductance as a coil of breadth d and depth b (see Fig. 7)

Hence for the same mean radius and number of turns a flat helical spiral of one layer should have the same inductance as a cylindrical helix of one layer.

Numerous formulæ have been given for the inductance of single-layer spirals having various dimension ratios. The expression given by

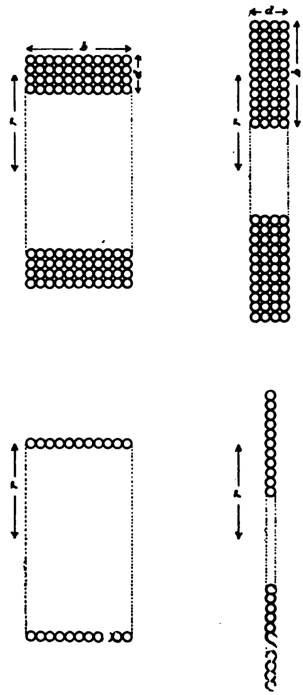

FIG. 7.—Coils of Equal Inductance having same Mean Radius and Number of Turns.

Maxwell was shown by Weinstein to be not quite correct, and he gave another which was subsequently simplified by Stefan, as follows :—

$$L = 4\pi r n^2 \left\{ \left(1 + \frac{3b^2 + d^2}{96 r^2}\right) \log_e \frac{8r}{\sqrt{b^2 + d^2}} - C_1 + \frac{b^2}{16 r^2} C_2 \right\} \quad . \quad . \quad (11)$$

where L is the inductance for steady currents, r is the mean radius of the coil, b is the breadth and d the depth of the section (rectangular) and C_1 and C_2 are constants, which are functions of b/d or d/b, which have been tabulated in Table II.

The above formula is, however, obtained on the supposition that the wire is square-sectioned wire with infinitely thin insulation, and packed so as to fill up the whole of the rectangular space $b \times d$. As, however, the wire used is generally round wire with thick insulation,

TABLE II.

b/d or d/b.	C_1.	C.	b/d or d/b.	C_1.	C_2.
0·00	0·50000	0·1250	0·55	0·80815	0·3437
0·05	0·54899	0·1269	0·60	0·81823	0·3839
0·10	0·59243	0·1325	0·65	0·82648	0·4274
0·15	0·63102	0·1418	0·70	0·83311	0·4739
0·20	0·66520	0·1548	0·75	0·83831	0·5234
0·25	0·69532	0·1714	0·80	0·84225	0·5760
0·30	0·72172	0·1916	0·85	0·84509	0·6317
0·35	0·74469	0·2152	0·90	0·86697	0·6902
0·40	0·76454	0·2423	0·95	0·84801	0·7518
0·45	0·78154	0·2728	1·00	0·84834	0·8162
0·50	0·79600	0·3066	—	—	—

and does not fill up the whole space, three corrections to the above formula have to be made which are all additive, and may be combined into a single correction ΔL, so that the actual inductance is $L + \Delta L$ where ΔL has the value—

$$\Delta L = 4\pi r n \left\{ \log_e \frac{D}{d} + 0{\cdot}1386 + C \right\} \quad . \quad . \quad . \quad . \quad (12)$$

The first term takes account of the fact that the wire is round and of diameter d, and insulated up to a diameter D. The second term reduces from square to round section, and the third term, C, takes account of the difference in the mutual inductance of the various terms when the wire is of round section from that when it is of square section and having no insulation. Maxwell considered that this term C was constant, and had a value $-0{\cdot}01971$, but Rosa has shown in Bulletin No. 3, page 37, of the Bulletins issued by the Bureau of Standards, Washington, U.S.A., that C is a function of the number of layers and windings as given in Table III.*

Flat spirals constitute very convenient forms of inductance, and have been already largely used in radiotelegraphy as inductances. Up to the present the author believes no one has pointed out any way in which the inductance of any given flat spiral of insulated wire can be easily predetermined with sufficient accuracy for all practical purposes.

Inductance of Flat Spirals.—It is clear, however, that the above Stefan formula and correction enables us to calculate the inductance of cylindrical and also of flat spiral coils, provided that the breadth b or depth d are not large compared with the mean radius r. Thus, for instance, we can employ the above formulæ to predetermine the induc-

* Every one engaged in electrophysical research is indebted sooner or later to these Bulletins of the Bureau of Standards. They contain much valuable information in an easily accessible form.

TABLE III.

Turns	Layers.	C.
2	1	0·006528
3	1	0·009045
4	2	0·016910
1	1	0·010350
8	2	0·013350
10	1	0·012760
20	1	0·013570
16	4	0·015120
100	10	0·017130
400	20 × 20	0·017640
1,000	50 × 20	0·017780
Infinite	—	0·018060

tance of a flat spiral of one layer and 10 turns with mean radius 10 cms., the turns being closely adjacent and made of round copper wire insulated up to a diameter of 5 mm., the ratio D/d being 2·6.

Then we have—

$$r = 10, \quad b = 0{\cdot}5, \quad d = 5{\cdot}0,$$
$$b^2 + d^2 = 25{\cdot}25, \quad \sqrt{b^2 + d^2} = 5{\cdot}025,$$
$$8\,r = 80, \quad \frac{8\,r}{\sqrt{b^2 + d^2}} = \frac{80}{5{\cdot}025} = 15{\cdot}92,$$
$$\log_e 15{\cdot}92 = 2{\cdot}7676, \quad 4\,\pi\,n^2\,r = 12566,$$
$$1 + \frac{3\,b^2 + d^2}{96\,r^2} = 1{\cdot}0026.$$

Then—

$$\begin{aligned} L &= 12566\left\{1{\cdot}0026 \times 2{\cdot}7676 - 0{\cdot}59243 + 0{\cdot}1325 \times 0{\cdot}00016\right\} \\ &= 12566 \times 2{\cdot}18236 = 27{,}424 \text{ cms.} \end{aligned}$$

also—

$$\Delta\,L = 1256{\cdot}6\left\{\log_e 2{\cdot}6 + 0{\cdot}1386 + 0{\cdot}01276\right\} = 1{,}382 \text{ cms.,}$$

and—

$$L + \Delta\,L = 28{,}806 \text{ cms.}$$

In order to check the accuracy of this predetermination a flat spiral was made by winding indiarubber-covered $\frac{7}{22}$ wire on a flat board, as shown in Fig. 8. The total length of wire used was 628·3 cms., or 21 ft. The outside turn was 25 cms. in diameter, and the inside 15 cms. The inductance was measured with the cymometer as follows: An oil condenser of capacity 0·00129 microfarad was joined up in series with a rectangle of wire having a calculated inductance of 5,000 cms. The oscillation constant of this circuit was then—

$$\sqrt{5{,}000 \times 0{\cdot}00129} = 2{\cdot}54.$$

Two similar spirals made as above described were then inserted in series in this oscillatory circuit, and the corrected oscillation constant found to be 8·97. Hence the inductance L of the spiral is obtained from the equation—

$$(5{,}000 + 2\,L) \times 0{\cdot}00129 = (8{\cdot}97)^2 = 80{\cdot}46.$$

Hence the inductance of each spiral is $\frac{1}{2}(62372 - 5000) = 28{,}686$ cms. Accordingly theory predicts the inductance to be 28,806 cms., and experiment finds it to be 28,686 cms., a difference of about one-third of 1 per cent.

Another test was made with a coil of 15 turns of $\frac{3}{32}$ wire insulated up to a diameter of 0·43 cm. Equal lengths of wire were wound up

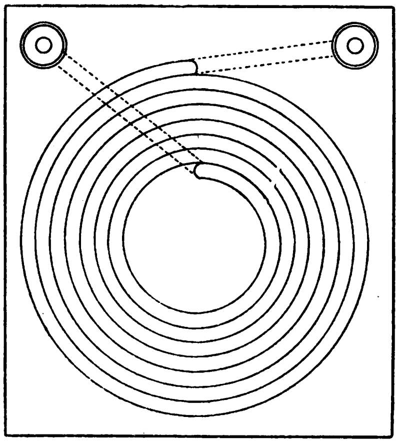

FIG. 8.—Flat Spiral Inductance Coil.

respectively into a flat helix of 15 turns and also into a cylindrical coil of 15 turns, the mean radius in both cases being nearly 7·25 cms., and the turns closely adjacent. We have then $r = 7{\cdot}25$ cms., $n = 15$, and $b = 0{\cdot}43$, $d = 6{\cdot}5$ for flat spiral and $b = 6{\cdot}5$, $d = 0{\cdot}43$ for cylindrical coil. Hence—

$$r^2 = 52{\cdot}56 \quad \sqrt{b^2 + c^2} = 6{\cdot}5,$$

$$\log_e \frac{8\,r}{\sqrt{b^2 + c^2}} = 2{\cdot}188, \quad 4\,\pi\,n\,r^2 = 20488,$$

also for the ratio $b/d = d/b = 1/15$ we have—

$$C_1 = 0{\cdot}562 \text{ and } C_2 = 0{\cdot}132 \text{ from Table II.}$$

Again, $1 + \frac{3\,b^2 + d^2}{96\,r^2} = 1{\cdot}009$ for the flat spiral, and 1·025 for the cylindrical coil, whilst $\frac{b^2}{16\,r^2} = 0{\cdot}00024$ for the flat spiral, and 0·05 for the cylindrical.

Hence $L = 33{,}723$ cms. for the flat spiral, and $L = 34{,}584$ cms. for the cylindrical coil. The correction ΔL is the same in both cases. We have $D = 0{\cdot}43$, $d = 0{\cdot}15$, $D/d = 3$, $\log_e D/d = 1{\cdot}09852$, and $4 \pi n r = 1366$. Therefore—

$$\Delta L = 1366 \left\{ 1{\cdot}09852 + 0{\cdot}13806 + 0{\cdot}01351 \right\} = 1366 \times 1{\cdot}25 = 1707.$$

Accordingly the predetermined inductances are 35,430 cms. for the flat spiral, and 36,291 cms. for the cylindrical coil. The actual values measured as above described by the cymometer were 36,085 cms. for the flat spiral, and 37,340 cms. for the cylindrical coil. The difference in the predetermined values for the flat spiral and the solenoid of same mean radius and number of turns is due to the fact that the Stefan

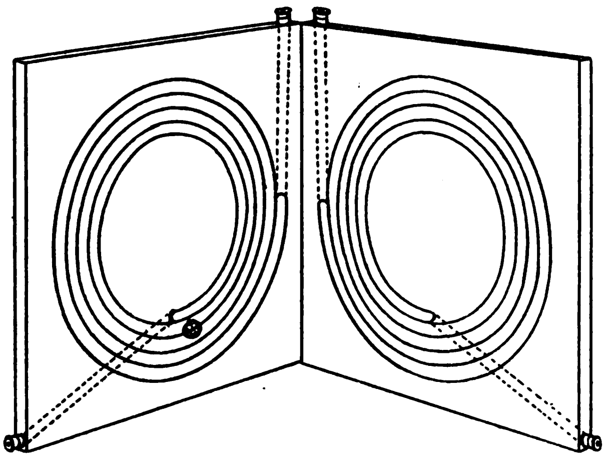

FIG. 9.—Folding Book Form of Flat Spiral Inductance Coil.

formula is not symmetrical in b and d, and hence does not give exact values unless b and d are both small compared with r.

The difference in the measured value is also due to a small difference, about 2 per cent., in the mean radii of the flat spiral and solenoidal coil.

The agreement, however, is sufficiently close to show that for approximate predeterminations of the inductance of flat spirals the Stefan formula can be employed with certain restrictions. Several other tests have been made confirming this conclusion. Very convenient forms of variable inductance without sliding contacts can be made with flat spiral coils—for instance, two such spirals may be mounted on hinged boards so as to come more or less into apposition with each other (see Fig. 9). The two spirals can be joined up in series by a flexible connection, so that when the boards are shut up like a book the currents in the two spirals oppose each other, and the joint

effect is a minimum inductance. When, however, the boards are opened out the inductances of the two coils are added, and the joint inductance is a maximum. We can, therefore, by opening the hinged boards more or less adjust the inductance in about the ratio of 8 : 1 without altering the total resistance or introducing a rubbing contact.

We can also mount four spirals on two boards pivoted at the centre so as to cross each other, and join up these four coils so that when the upper board is turned round through 180° the inductance varies from a minimum to a maximum value over a considerable range (see Fig. 10). Such arrangements are useful in tuning coils for radio-telegraphic receivers and transmitters. A receiver made on these

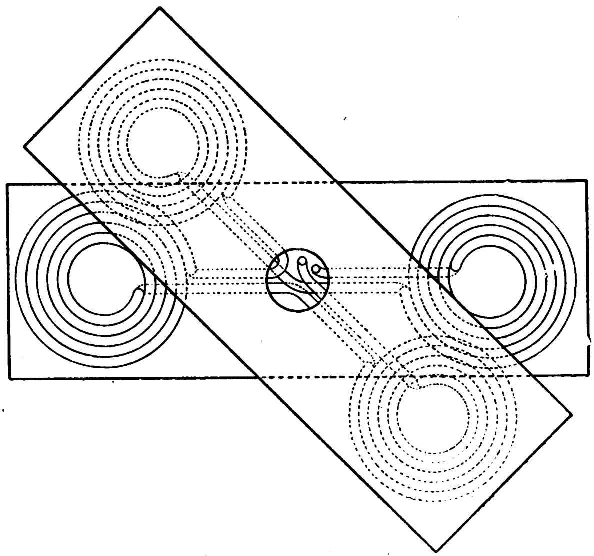

FIG. 10.—Flat Spiral Variable Inductance Coil.

principles, designed by the author for the radiotelegraphic stations at University and King's Colleges, is exhibited.

A quadruple flat spiral coil is shown of which the inductance can be varied from 28,000 cms. to about 330,000 cms. without any change in resistance. A pair of flat spirals moving over one another with planes parallel, has the peculiar characteristic that the mutual inductance can be varied from a maximum value down to absolute zero by quite a small sliding of one coil over the other. Taking advantage of these facts with regard to flat spirals, Mr. Dyke has ingeniously constructed a very compact radio-telegraphic receiving circuit consisting of variable inductance, oscillation transformer of variable coupling and variable condenser, with which he can detect electric waves of any wave-length between 300 and 4,000 metres.

Measurement of Spark Frequency.—Another quantity of great importance for which hitherto no accurate means of measurement has existed is the measurement of spark frequency. When an induction coil or transformer is employed to charge a condenser which is then discharged across a spark-gap, these discharges may succeed each other from 50 to several hundred per second, and we require to determine their frequency and regularity or irregularity.

Some years ago the author devised a method in which the spark or another simultaneous spark was made to pierce a rapidly moving telegraphic tape.* This method, however, had a very limited application. More recently the author has devised a means of recording the spark frequency by photography by which it is very easy to record up to any frequency obtainable without even approaching the spark to be tested,

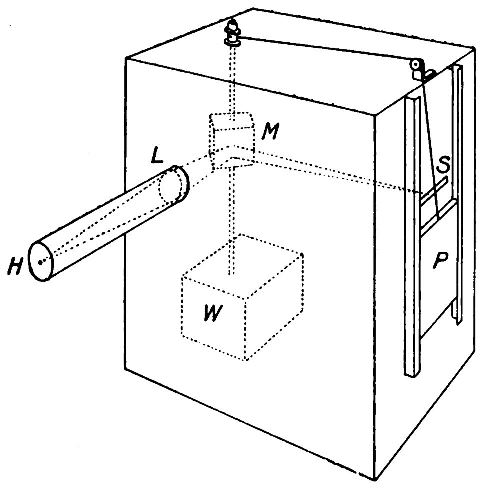

FIG. 11.—Photographic Spark Counter (Fleming).

provided only that an image of it can be thrown by means of a lens upon a pinhole.

Photographic Spark Counter.—This improved photographic spark counter is constructed in the following manner: A well-made wooden box, perfectly light, tight, and blackened in the interior, with a door on one side, is furnished with a good rapid rectilinear camera lens *L* at one side (see Fig. 11). The lens tube has the usual iris diaphragm. The box is 38 cms. high, 38 cms. wide, and 25 cms. broad. The lens tube is prolonged by another tube closed at the end, but with a very small hole *H* in the cover. In the interior of the box is a train of clockwork *W* which drives round a vertical shaft about 18 times per minute. This

* See J. A. Fleming, "Principles of Electric Wave Telegraphy," chap. ii. § 15, p. 157.

shaft carries a cubical block of aluminium to the four sides of which is affixed carefully flatted glass plate silvered on the surface. This cubical mirror M is so placed that it receives a ray passing through the small hole in the collimator tube and gathered by the lens and reflects it at right angles, or nearly so, so that the ray falls on a slit S in the side of the box about 1 cm. wide and 7 or 8 cms. in length. Outside the box a plate carrier P slides down in grooves in such fashion that when the slide is drawn out the exposed sensitive plate glides past the slit in the box. The same clockwork that drives round the cubical mirror lowers the photographic plate at a uniform rate so that it travels over the slit. If, then, the pinhole in the end of the collimator is illuminated intermittently by the image of a spark thrown on it, then the ray passing through the lens and reflected from a revolving mirror is brought to a focus on the photographic plate, and sweeps across it, imprinting an image on the plate at intervals depending on the frequency of the spark.

Four times in each revolution of the cubical mirror block a train of images sweeps over the gradually falling photographic plate, and when this is developed we find it covered with rows of black spots, each of which denotes the occurrence of a spark. It is clear that the number of sparks per second bears a definite relation to the speed of the revolution of the mirror and to the angle subtended by the slit at the mirror, and to the speed at which the photographic plate is lowered past the slit in the camera. It is convenient to have a mark on the photographic plate carrier, and a scale at the side to determine the time T taken by the plate to move down, say 10 cms.

Let l be the length of the slit which in the camera designed by the author is 7·9 cms., and let θ be the angle in degrees which this slit subtends at the mirror surface. Then $\theta/360$ is the fraction of one complete revolution, which the reflected ray turns through in sweeping over a slit of length l.

If the photographic plate descends a distance d cms. per revolution of the mirror block, and takes a time T seconds to descend a distance D cms. then the time taken by the mirror to turn through one revolution is $\mathrm{T}\,d/\mathrm{D}$, and to turn through 1° it is $\mathrm{T}\,d/\mathrm{D}\,360$, and to turn through an angle θ is $\mathrm{T}\,d\,\theta/\mathrm{D}\,360$. Hence half this time, or $\frac{1}{2}\frac{\mathrm{T}\,d\,\theta}{360\,\mathrm{D}}$ is the time taken for the ray to sweep over the slit of length l.

Hence the time interval t corresponding to a length of 1 cm. on the photographic plate is $t = \frac{\mathrm{T}\,d\,\theta}{l\,\mathrm{D}\,720} = \mathrm{C\,T}$ seconds. If, then, there are N spark images on the plate in M rows the average number per row is N/M, and the average space interval in centimetres between images is W M/N, where W is the width of the plate in centimetres.

Therefore W M C T/N is the average time interval in seconds between the sparks, or N/M W C T is the spark frequency. In the spark counter constructed for the author by Mr. Dyke the constant

C is equal to 0·00102, or very nearly $\frac{1}{1000}$, and the spark frequency n is given by the formula—

$$n = \frac{\textit{total number of spark images on plate}}{\textit{number of rows of images} \times 0{\cdot}00102\,\mathrm{T} \times 7{\cdot}9}$$
$$= \frac{1{,}000}{8\,\mathrm{T}} \times \frac{\textit{number of spark images on plate}}{\textit{number of rows of images}} \quad . \quad . \quad . \quad . \quad (13)$$

The formula is checked by the following device: On the shaft of an electric motor is placed a sheet tin disc, 2 ft. in diameter, having four holes an inch in diameter near the edge at quadrantal positions. Behind the disc is placed a small arc lamp so that the light shines through these holes. When the motor is set in revolution with a speed of 3,000 revs. per minute and its speed carefully determined with a tachometer we have flashes of light emitted by the arc through the holes at the rate of about 200 per second.

If we treat these flashes as if they were sparks and photograph them with the spark counter we then find on developing the plate a number of black dots, which are the images of the collimator hole, intermittently illuminated by the flashes coming at a known rate per second (see Fig. 12). On applying the formula given above to calculate the number of flashes from the number of images, we find an agreement with the actual number within 1 per cent. Such a control plate gives us, therefore, the means of confirming the accuracy of the formula and testing the photographic counter.

When such a spark counter is used to photograph the oscillatory spark at the spark balls of a radiotelegraphic transmitter we find that the results are extraordinarily different, according to the nature of the potential generator used, whether induction coil or transformer; also on the nature of the interrupter if a coil is used, and especially upon the length of the spark-gap, and whether it has an air blast applied to or not. A number of photographs are exhibited taken with this spark counter, which reveal for the first time to the eye the processes actually taking place in the spark-gap of a radiotelegraphic transmitter. The first series of photographs are taken of the spark in the transmitter of the wireless telegraph plant at University College, London. This consists of a motor-generator 1·5-k.w. size, which takes direct current at 220 volts from St. Pancras supply, and converts it into alternating current of frequency 100 and voltage 140.

This is supplied to a 1-k.w. transformer which steps up the voltage to 20,000, and this voltage charges a glass plate condenser of 0·0139 microfarad capacity, and discharges across a spark-gap between two brass discs or balls capable of being varied in distance. If we employ a fairly long spark-gap of 5 or 6 mm., and photograph the spark, we obtain a plate as in Figs. 12 and 15. There is a spark discharge each half period near the instant of maximum voltage. Hence, with a frequency of 100 there are 200 sparks per second. If we introduce much inductance into the low-tension side of the transformer, and

SPARK PHOTOGRAPHS—1-K.W. TRANSFORMER.

Spark gap not blown on. Blown on.

5·0 mm.

Large inductance in primary circuit of transformer.

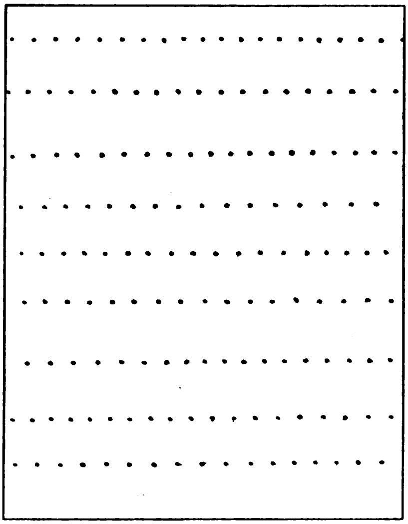

FIG. 12.

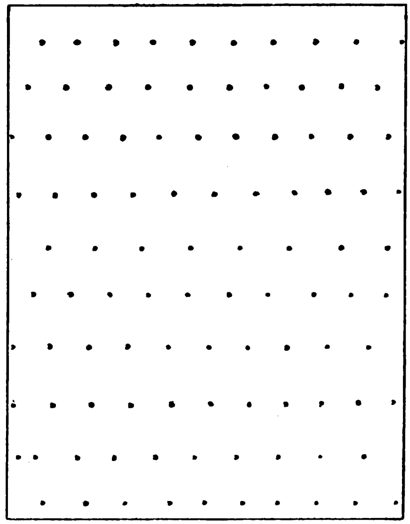

FIG. 13.

Wien Discharger. 11 gaps, 0·1 mm. each.

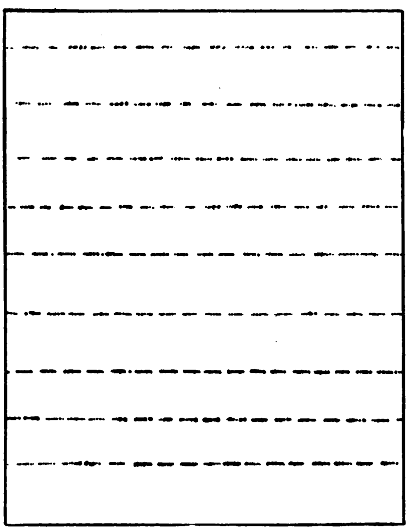

FIG. 14.

5·0 mm. small primy. indnce

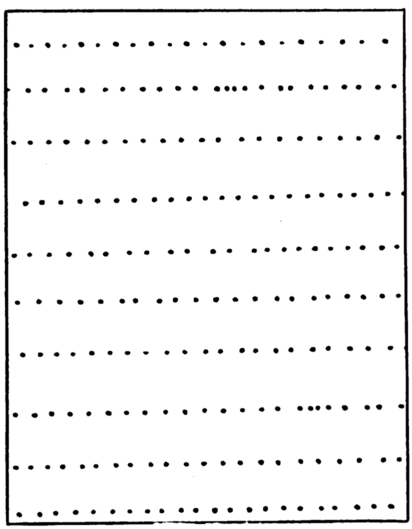

FIG. 15.

sometimes if we allow an air blast to impinge on the gap, each alternate discharge is suppressed, and we obtain a result as in Fig. 13, in which there is only one discharge per complete period. The full reasons for this have not yet been discovered.

If we take a smaller spark-gap, say 2 or 3 mm., then the plate reveals quite a different state of affairs which may be called the phenomenon of multiple sparks. In each half period there are 3, 4, 5, or more sparks following each other. The explanation of this is as follows: As the potential difference of the spark balls increases a point is reached at which a discharge takes place, but after this discharge the gap is left ionised, and the potential difference continues to rise. Hence a second discharge takes place, which is followed by a third, and so on, until the falling potential difference of the balls reduces the electric force in the gap to a point at which the discharge will not pass. This occurs each half period (see Figs. 16 to 23 inclusive).*

If the spark-gap is made still smaller, say 1 or 0·5 mm., this phenomenon is emphasised. Each half period we have rapidly repeated discharges 10, 20, or more, and these trains of discharges may even be almost uninterrupted (see Fig. 16). When the spark-gap is made very short, then a true arc discharge is often set up, which reduces the potential difference of the balls so much that often all oscillations are wiped out (see Fig. 17).

Numerous experiments have also been tried of the effect of an air blast upon spark discharges of various lengths. The effect of an air blast upon a short spark is generally to reduce the number of discharges per semi-period, but to increase the R.M.S. value of the discharge current. The air blast blows away the highly ionised air left between the balls after each discharge, but it raises the potential difference of the balls corresponding to each discharge, and hence increases the charge put into the condenser each time, although it decreases the number of discharges. This difference is shown in the left and right-hand photographs respectively in Figs. 16 to 23. It will be seen, therefore, that for short spark-gaps the effects taking place are complicated by a number of factors. Moreover, it will be seen that even although the frequency of the transformer remains constant the time interval between each spark is not by any means constant. This is because the exact voltage at which discharge takes place depends upon the state of ionisation of the air-gap left after the previous discharge. Accordingly this spark counter shows us the futility of all plans for effecting resonance between two stations depending upon syntonisation of the spark frequency and not the oscillation frequency. It has been again and again proposed to employ in the receiver circuits a monotone telephone most sensitive, say, to

* The engravings of these photographs illustrating this paper do not reproduce very completely the negatives themselves. The short, black lines in Figs. 14, 16, 17 and others are in reality composed of closely adjacent or overlapping dots, which are each the image of the pinhole photographed on the plate progressively. Each such dot represents an illumination of the pinhole by an instantaneous oscillatory spark.

SPARK PHOTOGRAPHS—1-K.W. TRANSFORMER.

Spark-gap not blown on. Blown on.

0·5 mm.

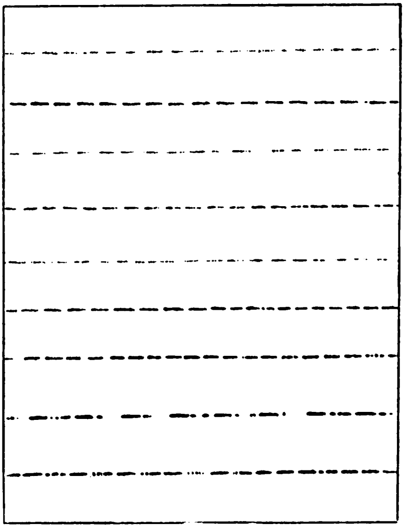

FIG 16.

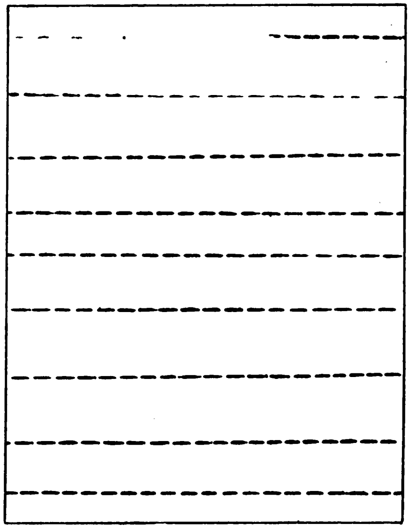

FIG. 17.

2·0 mm.

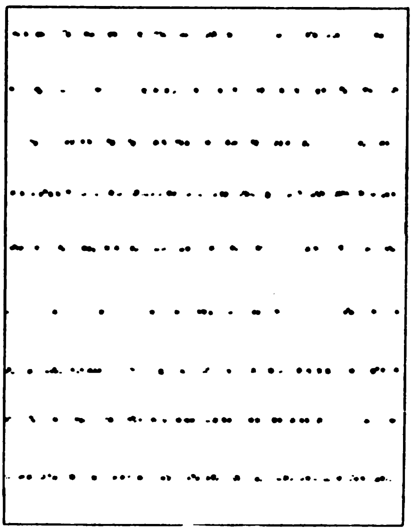

FIG. 18.

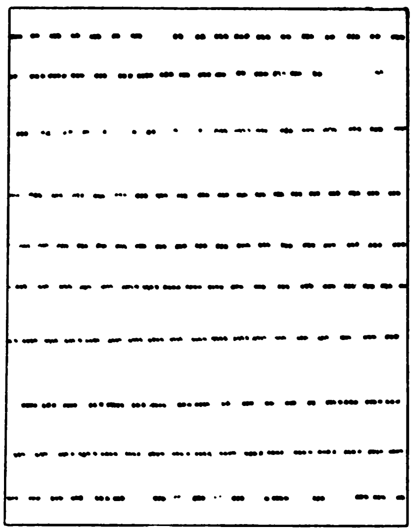

FIG. 19.

SPARK PHOTOGRAPHS—1-K.W. TRANSFORMER.

Spark-gap not blown on. Blown on.

2·5 mm

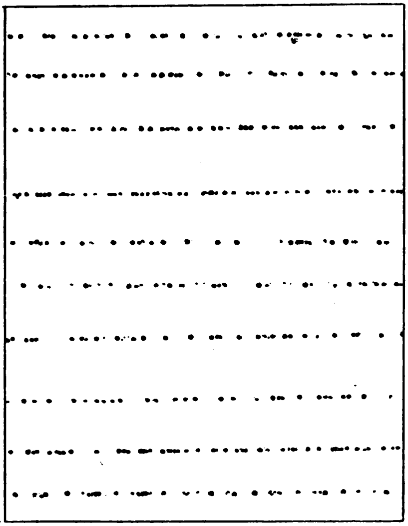

FIG. 20.

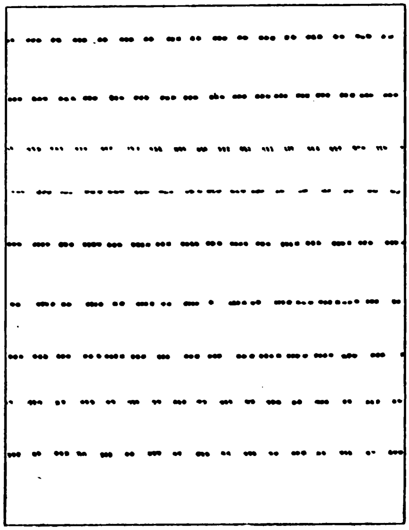

FIG. 21.

3·0 mm.

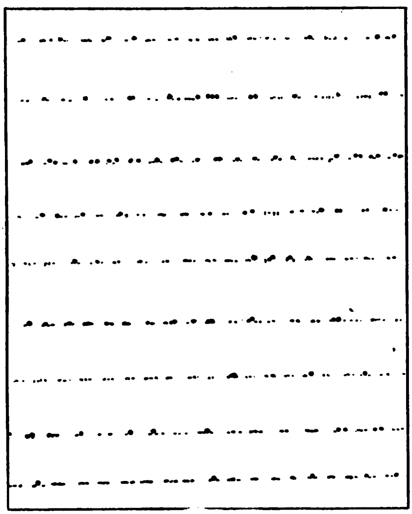

FIG. 22.

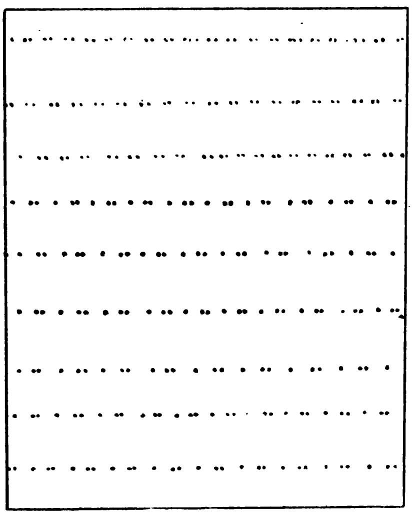

FIG. 23.

currents or trains coming at a frequency of 100 or 200 per second, and to employ in the transmitter a correspond-spark-frequency. But since this spark frequency is not constant, no true resonance effects can be obtained.

The same effect is seen in a more marked manner when photographing the spark of an ordinary induction coil working with a hammer or mercury break. The usual 10-in. induction coil had its secondary spark balls short-circuited by a condenser consisting of one or more Leyden jars and an inductive circuit, as in the case of a radiotelegraphic transmitter, and the spark was then photographed with the spark counter, using in the first place the ordinary hammer break, and in the second place a mercury turbine break working in coal-gas. If the spark-length is considerable, say 5 to 6 mm., then the photographs show that there is one spark per interruption of the primary circuit, whether working with the mercury or the hammer break, but that in the case of the hammer break the time interval between the sparks is extremely irregular, showing that there is no kind of isochronism in the spark frequency (see Figs. 24 to 31). If the spark-gap is gradually reduced successively to 4, 3, 2, or 1 mm. in length, then the phenomenon of multiple sparks makes its appearance. Groups of 4, 5, 6 or more sparks occur at each interruption, and when the spark-length is reduced to 1 mm. or less, each interruption of the primary circuit of the coil is accompanied by the production of a very long train sometimes containing hundreds of spark discharges, each of which consists, of course, of a train of electrical oscillations. These may even run together into an almost unbroken train for several periods, thus producing almost the effect of undamped oscillations (see Figs. 24 and 25). It will also be noticed, on examining these photographs, that sometimes the oscillations are entirely wiped out for a certain time. This is the result, possibly, of a true electric arc set up between the balls, and until this is extinguished the true oscillatory discharge cannot take place. It is always found that when the short spark-gap is subjected to an air blast, the discharges become more regular and the R.M.S. value of the discharge current increases, due to an increase in the discharge voltage. Nevertheless, we cannot conclude that the voltage to which the condenser is charged is always that corresponding to the spark-length. Thus, for instance, although 1 mm. spark-gap may correspond to a spark voltage, say, of 4,000 volts as determined by experiments made with single sparks, yet it does not follow that a condenser connected to that spark-gap will at every charge be charged to 4,000 volts, because the ionisation of the air in the spark-gap may greatly decrease the voltage required to bring about a discharge. These photographs, therefore, show the necessity for great caution in drawing any conclusions as to the number of discharges taking place per second, or the voltage at which they take place when the spark-gap is reduced below a certain length apart from the use of such a spark counter.

Some very interesting photographs have also been taken with this

SPARK PHOTOGRAPHS—10-IN. INDUCTION COIL, HAMMER BREAK.

Spark-gap not blown on. Blown on.

0·2 mm.

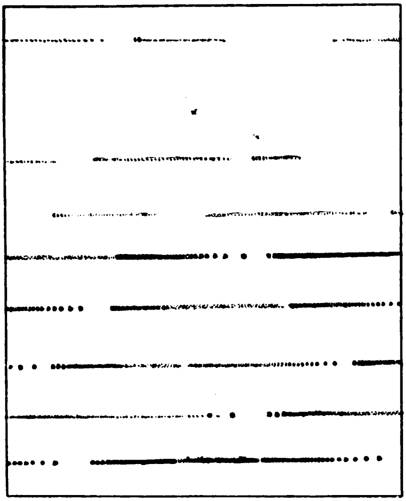

FIG. 24.

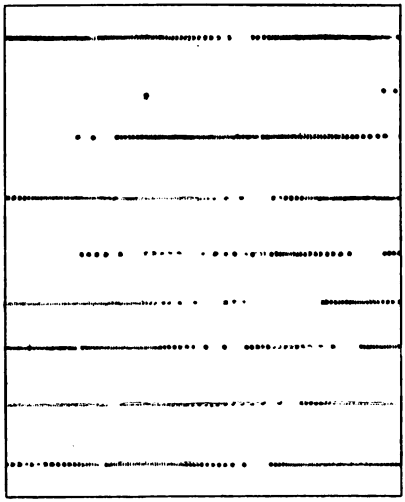

FIG. 25.

0·5 mm.

FIG. 26.

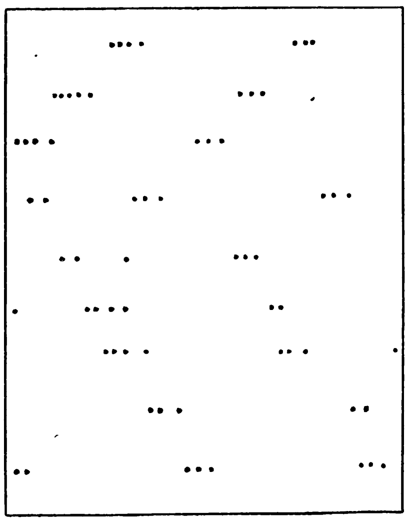

FIG. 27.

SPARK PHOTOGRAPHS—10-IN. INDUCTION COIL, HAMMER BREAK.

Spark-gap not blown on. Blown on.

1·0 mm.

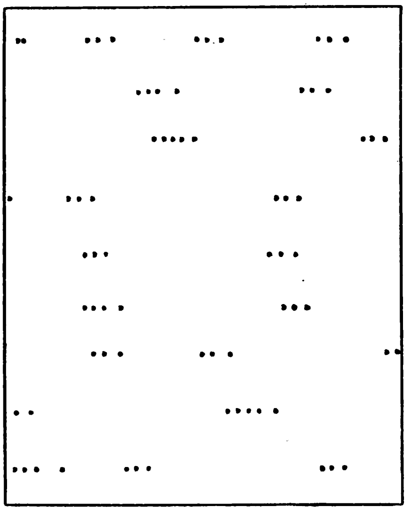

FIG. 28.

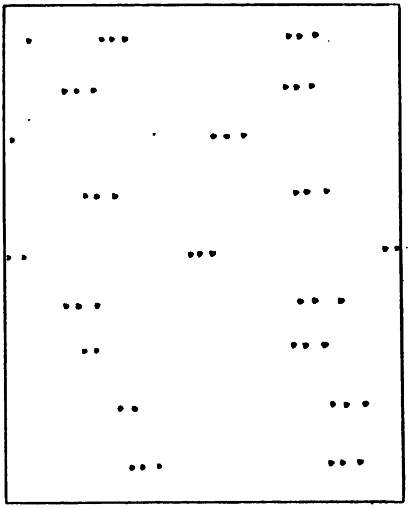

FIG. 29.

2·0 mm.

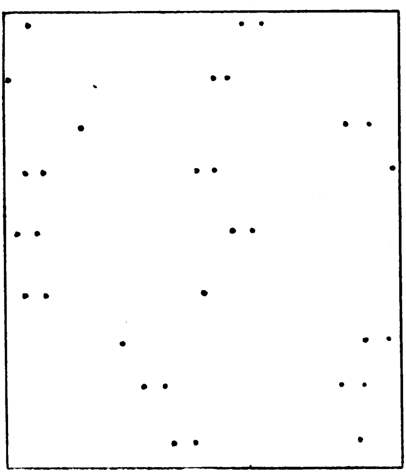

FIG. 30.

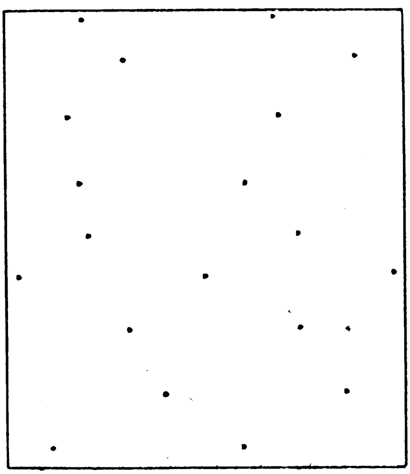

FIG. 31.

SPARK PHOTOGRAPHS—10-IN. INDUCTION COIL, MERCURY TURBINE BREAK.

Spark-gap not blown on. Blown on.

0·5 mm.

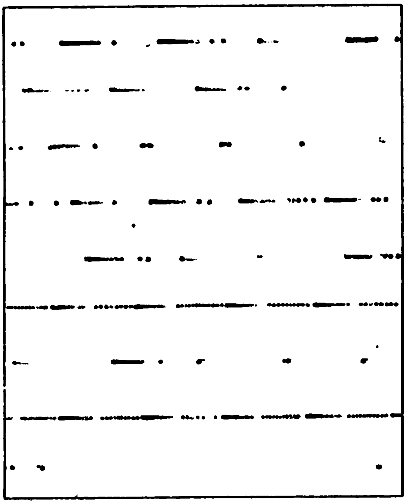

FIG. 32.

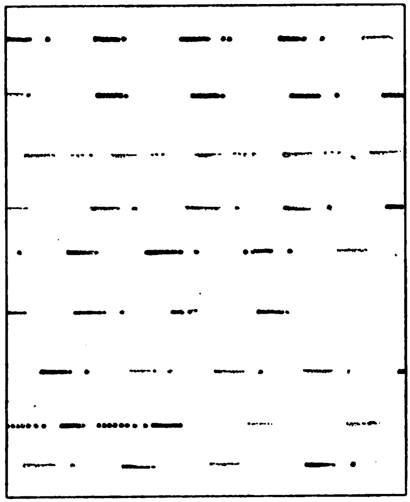

FIG. 33.

1·0 mm.

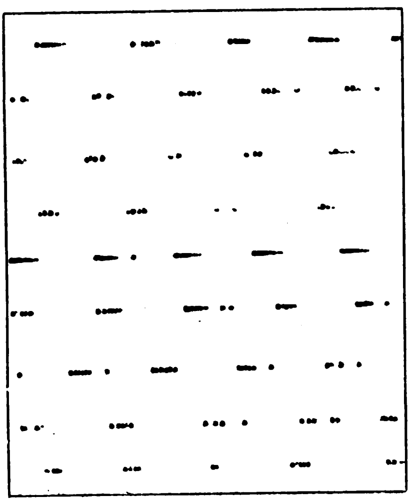

FIG. 34.

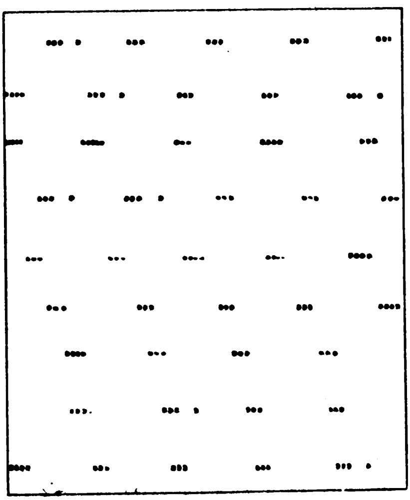

FIG. 35.

apparatus of the discharge produced by a quenched spark or Wien discharger of the type now used by the *Gesellschaft für drahtlose Telegraphie,* as described by Count von Arco in the *Electrician,* vol. 63, p. 461, 1909. This discharger consists of a number of copper discs with interposed mica rings, the surface of the copper discs being made extremely true and separated by a fraction of a millemetre. A series of ten or twelve of these discs are piled one on the top of the other, producing a compound spark-gap consisting of very short intervals. These short spark-gaps, as is well known, possess large damping power, and the discharge therefore consists of a series of very rapid discharges. As it is not possible to see the spark discharge

SPARK PHOTOGRAPHS—10-IN. INDUCTION COIL, MERCURY TURBINE BREAK.

Spark-gap not blown on. Blown on.

2·0 mm.

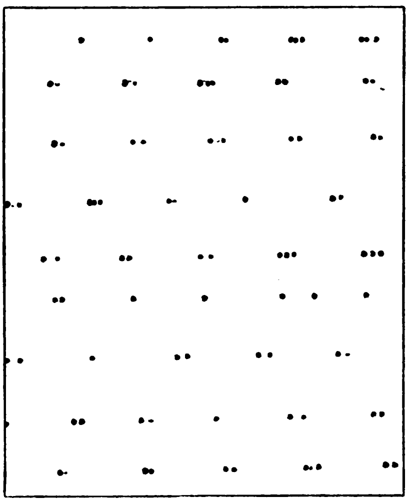

FIG. 36.

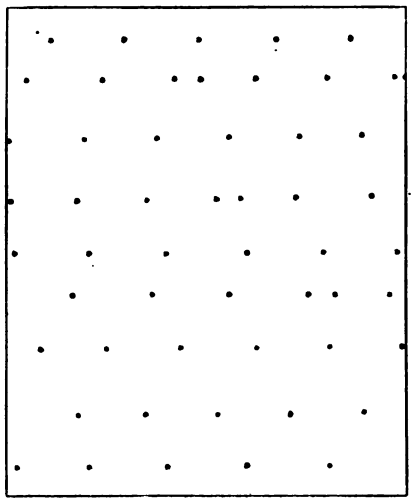

FIG. 37.

in the interior of this arrangement, a supplementary naked, very short spark-gap is joined in series with it, consisting of two brass points separated by a very short interval, so that visible sparks happen at this external spark-gap corresponding to each of the spark discharges in the interior of the copper disc discharger.

One photograph obtained is shown in Fig. 14. In the negative it is seen that it consists of groups of five or six or more discharges separated by very short intervals of time, the groups themselves being separated by slightly longer intervals of time. In the particular photograph shown these spark discharges are separated by an interval of time equal to about $\frac{1}{4000}$th of a second, and some forty discharges took place in a hundredth of a second. Hence although this discharger does not give

undamped oscillations it gives closely adjacent trains of oscillations, having therefore a relatively large mean square value.

It will be seen, therefore, that it is of great importance to apply a photographic spark counter of the type described to examine the nature of the discharge in all cases of spark telegraphy, and also in those cases in which any measurements are made of decrement or spark resistance where the length of the spark-gap may be varied between two experiments. It is quite fallacious to conclude that the number of discharges which take place between the spark balls of such a discharger when operated by means of a transformer or induction coil with mechanical break, can be deduced from the frequency of the alternator or from the speed of the break. The number of discharges which actually take place across the spark-gap may bear no definite relation at all to either the speed of the alternator or the speed of the interrupter.

Measurement of Wave-length and Decrement.—Two other important measurements peculiar to radiotelegraphy are the wave-length and damping or logarithmic decrement of the oscillations.

We require to know the frequency of the oscillations set up in the sending and in the receiving antenna, and also their logarithmic decrement.

The wave-length is measured by bringing into loose coupling with the antenna some other circuit having inductance and capacity, one or both of these elements being variable, and ascertaining what adjustment of these must be made to make the current in this secondary circuit a maximum.

In the author's cymometer the capacity consists of a sliding tube-condenser with ebonite dielectric, and the inductance of a spiral of copper wire embraced by a clamp, and the two are so arranged and united that one movement of a handle varies in the same proportion both the capacity of the sliding tube-condenser and the effective part of the inductance of the helix, the circuit of the two being completed by a wire in the form of a rectangle. The condition of maximum current is ascertained either by the brightest glow in a Neon vacuum tube connected across the terminals of the condenser, or by a hot-wire thermoelectric ammeter inserted in the circuit of the cymometer. A scale is so placed and divided that it shows on inspection the square root of the product of the capacity in microfarads and the inductance in centimetres included in the cymometer circuit, and this is called the *oscillation constant* ($O = \sqrt{CL}$) of the instrument for that setting. The corresponding frequency n is also shown, obtained from the equation—

$$n = \frac{5{\cdot}033 \times 10^6}{\sqrt{C\,L}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

and the corresponding wave-length λ in feet or metres from the equations—

$$\left.\begin{aligned} \lambda &= 195{\cdot}56 \times \sqrt{C\,L} \text{ feet} \\ &= 57{\cdot}6 \times \sqrt{C\,L} \text{ metres} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (15)$$

the capacity C being reckoned in microfarads and the inductance L in centimetres. These wave-length and frequency values are shown on the scale on which the oscillation constants are marked. In other wavemeters, such as that of Dönitz, the inductances are coils of wire of fixed inductance, and the capacity is an oil condenser with sector plates, the rotation of an axis moving the alternate plates attached to it more or less within the other fixed plates. The adjustment for maximum current is ascertained by the use of some form of hot-wire ammeter which is inserted directly, or else coupled inductively to the wavemeter circuit. The Dönitz instrument has the advantage that there is no moving or rubbing contact, but it has the disadvantage that its scale calibration for oscillation constant or wave-length is not equidivisional, and is varied with every change in the inductance coil.

When such a wavemeter is employed at the transmitting end it is easy to adjust its circuit in loose coupling with the sending antenna, and read the wave-length of the emitted wave on the cymometer scale, using a Neon tube or hot-wire ammeter as the detector of maximum current. When used in connection with the receiving antenna the oscillations are too feeble to be so detected, but we can do it by substituting for the Neon tube a rectifying detector of some kind in series with a high-resistance telephone.

The author has found that the most convenient detector for this purpose is the molybdenite-copper point rectifier of Professor G. W. Pierce. A small mass of molybdenite is held in a clip, and a copper point adjusted in light contact therewith. The contact has very effective unilateral conductivity, and rectifies the trains of oscillations so that they affect a high-resistance telephone (1,000 ohms) placed as a shunt across the condenser terminals of the cymometer. The wavelengths of the arriving waves can then be read off on the scale by adjusting the wavemeter circuits to give maximum sound in the telephone.

The cymometer or other wavemeter can also be employed to measure the decrement of the oscillations either in the sending or receiving antenna as follows:—

If we are measuring the decrement of the oscillations in the sending antenna, the first step is to plot a resonance curve by setting out as ordinates the value of the mean-square current (J^2) in the cymometer circuit corresponding to various values of the natural frequency (n) of that circuit for various settings of the capacity and inductance within such limits that n does not differ from the resonance frequency N by more than 5 per cent. Then if J_r^2 is the mean-square value of the maximum or resonance current in the cymometer circuit, and δ_2 is the decrement per semi-period of that circuit, and if δ_1 is the decrement of the oscillations in the antenna, we have by the usual Bjerknes formula *—

$$\delta_1 + \delta_2 = \pi \left(1 - \frac{n}{N}\right) \sqrt{\frac{J^2}{J_r^2 - J^2}} \quad . \quad . \quad . \quad . \quad . \quad (16)$$

* For the proof of this formula see "The Principles of Electric Wave Telegraphy," chap. iii. § 13.

Assuming, then, that the resonance curve is drawn with J^2 as ordinates, and n as abscissæ, we may select various values of n and J^2 and substitute them in the above formula provided that n is within 5 per cent. of N. We may shorten the calculation by selecting a single value of n such that $1 - \frac{n}{N} = 0{\cdot}05$ or $n = 95$ N/100, and determine the value of J^2 corresponding to this value of n.

Again, since the decrement of the cymometer circuit is given by the expression—

$$\delta_2 = \frac{R'}{4\, n\, L'} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

where R′ is the high-frequency resistance of that circuit, and L′ is its inductance corresponding to the frequency n, then for those types of wavemeter in which L′ is either constant or varies proportionately to R′ we have $\delta_2 = C/n$ where C is some constant for the instrument which can be determined by experiment.

Accordingly the semi-period decrement of the oscillations in the sending antenna is given by the expression—

$$\delta_1 = \frac{\pi}{20}\sqrt{\frac{1}{A^2 - 1}} - C/n \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (18)$$

where A^2 is the ratio of the mean-square values of the resonance current and the current corresponding to a frequency n which exist in the wavemeter circuit, n differing by 5 per cent. from the resonance frequency, and C being an instrumental constant of the wavemeter, viz., the value of $R'/4L'$ for that setting of the instrument corresponding to the frequency n.

Another method of obtaining the same quantity is to place the wavemeter or cymometer in contiguity to the circuit of which the decrement is required, and adjust the wavemeter circuit to resonance, and note the scale reading W on the wave-length scale corresponding to this setting. Then change the wavemeter setting both above and below this resonance position so that the mean-square value J^2 of the resonance current in the wavemeter circuit falls to half the value of the resonance mean-square current J_r. Then for this ratio $J^2 = \frac{1}{2} J_r^2$ the function—

$$\sqrt{\frac{J^2}{J_r^2 - J^2}} = 1.$$

If, then, w_1 and w_2 are the wave-length readings above and below W for which $J_r^2 = 2J^2$ we have the same equation—

$$1 - \frac{n}{N} = \frac{w_2 - w_1}{2\,W} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (19)$$

and therefore—

$$\delta_1 = \frac{\pi}{2}\,\frac{w_2 - w_1}{W} - C'\,W \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (20)$$

where $C' = \frac{R'}{L'}\,\frac{1}{4 \times 10^9}$ if W is reckoned in feet, and $C' = \frac{R'}{L'}\,\frac{1}{12 \times 10^8}$

if W is reckoned in metres; and R′ and L′ are the high-frequency resistance and inductance of the wavemeter circuit corresponding to the setting for W. The ratio R′/L′ can be determined by experiment.

There is no difficulty in determining in this manner the frequency and the decrement of the oscillations in the sending antenna. It is rather more difficult to do it for the receiving antenna, but it can be achieved as follows :—

The receiving appliance must consist of an inductance coil of adjustable inductance and a coil in series with it which forms the primary of an oscillation transformer, the secondary circuit of which is movable so as to vary over wide limits the coupling of the two circuits. The secondary circuit is completed by a condenser of variable capacity, and the terminals of this capacity are connected also through a rectifying contact such as the molybdenite-copper point and a high-resistance telephone in series with the latter.

The first step is to determine the ratio of the mean-square values of the resonance currents in the secondary circuit of the transformer when this secondary is set with various couplings or at different distances from the primary. This can be done by sending constant oscillations through the primary circuit and employing a low-resistance hot-wire ammeter in the secondary circuit, or else a high-resistance galvanometer in place of the telephone in series with a rectifying contact, the two being placed as a shunt across the condenser of the secondary circuit.

In this experiment we are really obtaining the value of the square of the coupling ($M^2/L\,N$) for the two circuits of the transformer. Having done this, we replace the telephone in the detector circuit and adjust the receiver to pick up the impinging waves of which it is desired to measure the decrement. The coupling of the two circuits of the transformer must then be reduced until the sound of the telephone just ceases to be heard. Let the mean-square current in the secondary circuit be then denoted by J_r^2. The tuning is then altered by changing the capacity in the secondary circuit sufficiently to make its natural frequency differ by 5 per cent. from the resonance frequency. The coupling is then strengthened again until the sound in the telephone is again just audible. Let the mean-square current in the secondary circuit be then denoted by J_1^2 and the mean-square current corresponding to the same coupling as the resonance current J_r be denoted by J^2. We may then assume that $J_r^2 = J_1^2$, and we have previously determined the ratio J_1^2 to J^2. Call the ratio A^2 for the couplings in question. Then it follows that—

$$J_r^2/J^2 = A^2 = J_1^2/J^2.$$

and the decrement of the oscillations in the receiving antenna will be given by the same formula (18) as before, viz. :—

$$\delta_1 = \frac{\pi}{20}\sqrt{\frac{1}{A^2 - 1}} - \delta_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (21)$$

To determine δ_2 or the decrement per semi-period of the secondary circuit of the oscillation transformer a second set of readings must be taken in the same manner, in which the decrement of the secondary circuit is artifically increased by the insertion in it of a fine wire of high-resistance r, the added decrement due to this is $\delta_2^1 = r'/4\, n\, L'$, where n is the frequency and L' the inductance of the secondary circuit. We then obtain a second equation :—

$$\delta_1 = \frac{\pi}{20}\sqrt{\frac{1}{A_1^2 - 1}} - \delta_2 - \delta^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (22)$$

and from equation (21) and (22) we can determine δ_1.

The process is rendered much more simple in these cases in which the current in the receiving antenna is large enough to affect directly a sensitive thermal microammeter such as Mr. Duddell's instrument, for we have no difficulty in determining the ratio J_r^2/J^2 for the two frequency settings of the receiver.

Measurement of Plant Efficiency.—The power of making the above described measurements renders it possible to obtain an estimate of the overall efficiency of a radiotelegraphic transmitter. By this term we mean the ratio of the mean power in watts emitted by the antenna in the form of long electric waves useful for radiotelegraphic purposes to the mean power given to the transformer or induction coil. If we take the case of an antenna inductively coupled to a condenser circuit, oscillations being set up by spark discharges and the condenser charged by an alternating-current transformer, then we have the following sources of energy dissipation. In the charging transformer we have the usual iron and copper losses. The power put into this transformer can be measured by a wattmeter provided the latter is correct for low power factors. In the condenser circuit we have copper losses due to the high-frequency resistance and also loss of power in the spark-gap due to spark resistance and light and noise. If the condenser has a capacity C and if we measure by the photographic spark counter the number of times it is charged per second, and if we determine in a way to be shown later on (in another paper) the mean voltage V to which the condenser is charged, then the quantity $\frac{N\,C\,V^2}{2}$ represents the power given to the condenser circuit.

If, then, we determine the decrement δ_1 of the condenser circuit this must be equal to the quantity $R'/4\, n\, L'$, where R' is the whole high-frequency resistance of the circuit, including that of the spark, and L is its inductance and n is the frequency. Any sources of loss in the condenser dielectric are included in this, as they are equivalent to an additional resistance. Hence, knowing the mean-square value J_1^2 of this condenser circuit current, we have as the expression for the power lost in it—

$$J_1^2 R' = J_1^2\, 4\, n\, L'\, \delta_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (23)$$

Again, if we measure the high-frequency resistance of the antenna and the current in it at various parts, we can find the total power loss due to the resistance of the antenna. If the current in it is distributed according to a sine law, and has a mean-square value J_2^2 at the base, then its average mean-square value is $\frac{1}{2}J_2^2$; and if R_2' is the high-frequency resistance of the antenna, then $\frac{1}{2}J_2^2 R'$ is the power wasted in it by resistance. The above expressions are in absolute electromagnetic units. If, however, we employ practical units and measure the currents in amperes, capacities in microfarads, potentials in volts, inductances in centimetres, and oscillation constants in $\sqrt{\text{microfarads} \times \text{centimetres}}$, and high-frequency resistance in ohms, then the equation of energy may be written in the following form:—

$$\frac{N}{2}\frac{C_1 V_1^2}{10^6} - \frac{O_1}{50}\frac{A_1^2 \delta_1}{C_1} - \frac{A_2}{2}R_2' = W \quad . \quad . \quad . \quad . \quad . \quad (24)$$

Where—

W = Radiation from the antenna in watts.
N = Number of spark discharges per second.
C_1 = Primary capacity in microfarads.
V_1 = Mean spark potential in volts.
A_1 = R.M.S. value of condenser current.
δ_1 = Mean decrement of condenser circuit.
O_1 = Oscillation constant of system.
A_2 = R.M.S. value of antenna current at earthed end.
R' = High-frequency resistance of antenna.

If P = Power given to changing transformer, then W/P is the overall efficiency of the transmitter.

All the above quantities can be measured for any actual transmitter with an inductively coupled antenna.

It is to be noticed that the decrement δ_1 includes any losses in the condenser.

The following figures give the experimentally determined values of the various constants and quantities for an inductively coupled spark transmitter in the Pender Electrical Laboratory of University College, London, for one particular adjustment and spark-gap. The plant consists of a rotary transformer by Crompton taking continuous current from a storage battery at 220 volts, and giving alternating current of a frequency of 100 at 150 volts. This is transformed up by an oil-insulated transformer to 15,000 or 20,000 volts, a pair of chokers or throttling inductances being interposed to stop arcing. The transformer charges a glass-plate condenser in oil, and this discharges through the primary of an oscillation transformer, the secondary of which is inserted in the antenna circuit. The spark-gap is 5 mm., and the sparks were counted with the photographic spark counter. The high-frequency resistance of the circuits of the oscillation transformer and of the antenna were determined experimentally. The antenna consists of four $\frac{2}{16}$ copper wires, each

about 60 ft. vertical and 90 ft. horizontal, and the length of secondary jigger wire (No. $\frac{7}{22}$) with connections, is 45 ft.—in all very nearly 195 ft. These wires are spaced 8 or 10 ft. apart. A resonance curve was taken with the cymometer, and the resistance decrement of the primary oscillation circuit determined and also the radiated wave-length 1,350 ft.), and the values are as follows:—

N = Spark frequency = 208.
C_1 = Capacity of condenser = 0·0139 microfarad.
V_1 = Spark voltage = 17,500 volts.
O = Oscillation constant = 6·9.
A_1 = Current in condenser circuit, R.M.S. value = 26·5 amperes.
λ_1 = Mean wave-length = 1,350 ft.
δ_1 = Decrement of condenser circuit = 0·0507.
A_2 = Antenna current, R.M.S. value = 4·9 amperes.
R_2 = High-frequency resistance of antenna circuit, 0·528 ohms for jigger secondary circuit, 0·21 ohms for antenna proper.
h = Length of whole antenna = 195 ft., 4 branches.
P = Power given to rotary transformer in watts = 2,620 watts.
W = Power in watts radiated from antenna = 78.

The value of W is calculated by the equation (24).

The efficiencies of the various portions of the apparatus were measured, and are set out in the efficiency chart (page 382) and power balance-sheet (page 383).

It will be seen that the efficiency of radiation, compared with the transformer intake, is about 10 per cent. Nevertheless there is a large loss in the chokers and rotary, due to these appliances not being properly designed for a low power factor. The rotary, chokers, and transformer are overloaded for current but not for power, and therefore the resistance losses are excessive. Hence the overall efficiency is very low, but the efficiency from transformer to antenna is about 10 per cent. The efficiency will unquestionably vary with the spark-length, and there is still a wide field of research to be covered in investigating the efficiencies corresponding to various conditions. It is, therefore, not more possible to speak of the efficiency of a radiotelegraphic transmitter without reference to some fraction of its full-rated capacity than it is to speak of the efficiency of a motor or transformer.

The right manner of defining it is by an efficiency curve, which shows the fraction of the power given to the transformer or induction coil, which is radiated as electromagnetic waves corresponding to some stated fraction of the full-load rating of that transformer or coil.

We shall doubtless be able to possess this information in course of time for various well-known types of transmitter.

It is clear, however, that in most types there is considerable room for improvement in efficiencies, and now that we have the means of testing the efficiency of each stage of the energy transformations, we

EFFICIENCY CHART FOR U.C.L. RADIOTELEGRAPHIC PLANT, WITH 5 MM. SPARK-GAP.

Rotary input,
2,620 watts.

Rotary output,
1,481 watts.

Rotary losses,
1,139 watts.

Rotary efficiency = 57 per cent.

Transmission losses,
71 watts.

Transformer input,
800 watts.

Choking coil losses,
610 watts.

Choker efficiency = 57 per cent.

Delivered to condenser,
445 watts.

Transformer resistance losses,
302 watts.

Transformer iron losses,
53 watts.

Transformer efficiency = 56 per cent.

Primary oscillation circuit losses,
351 watts.

Delivered to antenna,
94 watts.

Oscillation generator efficiency = 21 per cent.

Antenna resistance losses,
16 watts.

Radiation,
78 watts.

Antenna efficiency = 83 per cent.
Efficiency from transformer intake to radiation = 10 per cent.

can put our finger on the sources of energy dissipation with a view to their removal. We can therefore construct a power balance-sheet giving credit to the plant for so much power given to it, and making it debtor for such and such losses.

Thus, for instance, for the plant as above tested, we have the following balance-sheet :—

POWER BALANCE-SHEET FOR U.C.L. RADIOTELEGRAPHIC TRANSMITTER.

Cr.	Watts.	**Dr.**	Watts
By power given to rotary transformer in direct current ...	2,620	To Rotary losses	1,139
		„ Line losses	71
		„ Choker losses	610
		„ Transformer losses ...	355
		„ Oscillation circuit losses in condenser, spark-gap, and inductance ...	351
		„ Antenna resistance losses	16
		„ Balance, viz., power radiated as electro-magnetic waves ...	78
	2,620		2,620

The value of the power radiated, viz.—78 watts—can be checked in another way. It is well known that the field due to any linear oscillator of any form can be regarded as the resultant of the fields due to an infinity of elementary small Hertzian oscillators into which we may consider the antenna resolved. By applying Poynting's theorem to this case, the author has obtained the following formula for the energy radiated per second or the power emitted in watts as electro-magnetic radiation from an earthed antenna of length h sending out a wave of length λ, and having a mean-square current of A^2 amperes at the base :—

$$160 \frac{h^2}{\lambda^2} A_2^2 = W^* \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (25)$$

In this case $h = 195$ ft., and $\lambda = 1{,}350$ ft., and $A_2 = 4{\cdot}9$ amperes. Hence—

$$W = 160 \times \left(\frac{195}{1350}\right)^2 \times (4{\cdot}9)^2 = 80.$$

The radiation is therefore 80 watts, which agrees well with that formed by the actual measurement.

It is evident, then, that special designing is necessary to keep down the resistance losses not only in the rotary transformer, if used, but in the chokers, low-frequency transformer, and especially in the primary oscillation circuit.

* The proof of this formula is given in a forthcoming second edition of the author's treatise on "The Principles of Electric Wave Telegraphy and Telephony."

Greater care should be taken in the construction of primary oscillation transformers in the condenser circuit to avoid unnecessary resistance losses. The mere twisting together of bare wires or use of ordinary stranded cable, or even cables made of fine insulated wire, unless properly stranded, is not enough. The circuits should be made of fine insulated wire, single cotton covered, plaited in flat form, so that each wire is equally exposed. The chief source of the damping is undoubtedly in the spark itself. There is a wide field open for research in connection with various forms of spark discharges to ascertain which form conveys to the antenna the largest fraction of the power given out by the charging transformer.

Until this is done we cannot say in what direction improvement is possible. At the present time the actual radiation efficiency W/P is an unknown quantity for the majority of transmitters in use in radiotelegraphy, but now that we can count and record the spark frequency it will be possible to determine it with considerable accuracy.

We are then concerned in the next place with the efficiency of reception or the determination of the fraction of the radiated power which is captured by the receiving antenna.

The current in the receiving antenna is generally very small, but if it is large enough to be measured by a bolometer or any form of hot-wire ammeter such as the Duddell micro-ammeter with a heater of known resistance, then its mean-square value can be found and the power absorbed by the receiving antenna measured.

We can, from the known high-frequency resistance of the antenna and of the heater wire of the ammeter calculate the total power captured by it.

We have, then, the means of determining the ratio of power expended in signalling to the power expended in making the signal. Results of some measurements of this kind are recorded in Professor Tissot's interesting monograph, "Étude de la Résonance des Systèmes d'Antennes dans la Telegraphie sans fils."

In a certain case of a plain antenna 50 metres high and 4 mm. in diameter on board the French battleship *Henri IV.*, corresponding with a similar antenna at a distance of 1·7 kilometres, M. Tissot shows that, when the antenna was charged 20 times per second with a voltage equal to a 5-cm. spark, the mean radiation was 36 watts, or $1{\cdot}8 \times 10^7$ ergs per spark.

At a distance of 1 kilometre the energy picked up by the similar receiving antenna was 320 ergs per spark or 6,400 ergs per second.

At a distance of 1 kilometre from the sending antenna the mean spherical density of radiation was 28·6 ergs per second per square metre, and the receiving antenna therefore drained an area of 112 square metres equal to the product of its own height (50 metres) and a width of 2·25 metres, or 1·12 on either side. The receiving antenna thus appears to receive a greater amount of energy than is due to its own surface.

Even then the captured energy was only about $\frac{1}{600}$ of 1 per cent. of

that sent out, and since this latter was at most 5 per cent. or 10 per cent. or so of that given to the transmitter from the external source (battery or alternator), it is seen that the entire resultant efficiency was extremely small. Persons who hear these figures for the first time are apt to exclaim against the inefficiency of radiotelegraphy.

There is, however, an important point which must be noticed, to which M. Tissot has not referred.

The energy which is sent out from an antenna is not radiated equally in all directions. Hertz showed that if a small linear oscillator of electric moment ϕ is placed in the centre of a sphere of radius r large compared with the length of the oscillator, then if we divide the sphere into zones by lines of latitude, the energy sent out per period through a zone of width $d\theta$ and polar distance θ is equal to $\frac{4\phi^2\pi^4}{\lambda^3}\sin^3\theta\, d\theta$—where λ is the wave-length. The area of the zone is $2\pi r^2 \sin\theta\, d\theta$. Hence the energy density over the zone is $\frac{2\phi^2\pi^3}{r^2\lambda^3}\sin^2\theta$. Accordingly the radiation varies as the cube of the sine of the polar distance and the radiation density as the square. It is then easy to show that the

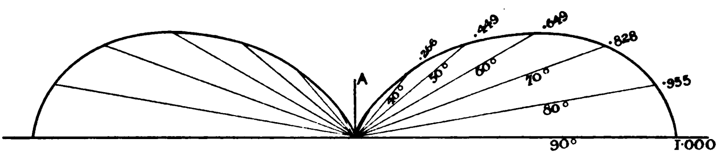

FIG. 38.—Section of Polar Radiation Surface for Vertical Antenna A.

horizontal radiation density along the equatorial plane is 1·5 times the mean spherical radiation density. If, then, we describe a curve whose polar equation is $r = C\sin^3\theta$ (see Fig. 38) its radii vectores will represent the radiation in different altitudes. It is therefore a most valuable property of the vertical antenna that it radiates in this manner chiefly along the earth and not up into the sky. Accordingly in making estimates of the percentage of emitted radiation which is captured we must take the mean horizontal and not the mean spherical radiation density into account. A polar curve of radiation, such as that shown in Fig. 38, was first given by Professor A. Blondel in 1903, in a paper read before the French Association for the Advancement of Science.

The matter which has to be borne in mind is that in radiotelegraphic stations the standby costs are so vastly greater than the cost of power actually used in signalling that even a large improvement in the efficiency of transmission would not greatly reduce the total costs.

Radiotelegraphic engineers have therefore quite rightly directed attention first to securing what may be called efficiency of operation—viz., certainty and speed in sending and receiving messages as well as in gaining freedom from interference—before dealing with questions of energy efficiency. Nevertheless these last must be considered in turn,

and the means of making exact quantitative measurements in connection with the subject is a matter of the greatest importance for its further development. It is hoped that the methods here described may be found to be of use and value for that purpose.

In conclusion, the author desires to record his thanks to those who have efficiently assisted him in this work.

Mr. G. B. Dyke, B.Sc., has rendered the most valuable assistance in making the spark counter and other appliances and in taking numerous spark photographs and measurements for the efficiency determinations; also in building up the experimental transmitter employed and overcoming difficulties.

Mr. F. G. Watermeyer, B.Sc., has worked with great care and perseverance at the high-frequency resistance experiments and capacity measurements; whilst Mr. H. W. Richardson, B.Sc., rendered some considerable aid in making the inductance measurements of the spirals. To their careful work the author is indebted for the numerical results here given.

EFFICIENCY OF SHORT-SPARK METHODS OF GENERATING ELECTRICAL OSCILLATIONS.

By W. H. ECCLES, D.Sc., and A. J. MAKOWER, M.A., Associate Member.

(*Paper received November* 10, *and read in London on December* 16, 1909.)

The evolution of the methods of generating powerful electrical oscillations for the purposes of wireless telegraphy has led in recent years to the gradual replacement of long spark-gaps and high potential differences by short gaps and comparatively low potential differences. For successful working with short gaps it is essential that the electrodes between which the discharge takes place should be kept cool, otherwise metal evaporates and an arc is established.

Many wireless telegraph engineers have taken part in this evolution; for example, Fessenden, in 1900, used as electrodes thin metal spheres full of circulating cold water, and Marconi used with great success heavy discharges passing between very close metal surfaces cooled by rapid rotation; the Telefunken engineers have developed another method wherein a series of short gaps between metal plates is employed. The extreme case is exemplified by the system advocated by von Lepel in which a potential of only 500 volts is used and the electrical discharge takes place between two water-cooled metal plates only a fraction of a millimeter apart.

In October, 1906, Max Wien * published an account of his investigations on the electrical discharge between metal surfaces placed very close together. In the experiments the gap between the surfaces was shunted in the usual manner by an inductance-capacity path, so that the discharge across it should be oscillatory. Under these circumstances the discharge that takes place is of such a nature that it becomes doubtful whether it should be described as an arc or as a series of sparks. There is no doubt that, if the inductance-capacity path were absent, the discharge across the short gap could properly be called an arc, but when the oscillatory path is present the discharge appears to change its nature and is accompanied by a peculiar hissing sound.

In Wien's experiments the phenomena occurring in the oscillatory circuit were examined by the aid of a resonant circuit coupled loosely with the shunt circuit, and this mode of investigation furnished a key

* *Deutsch. Phys. Gesell. Verh.*, Heft 20, pp. 486–489.

to the understanding of the real nature of the discharge. Now, when such a resonant circuit is coupled to a circuit that is traversed by electrical oscillations the presence of the resonant circuit involves electromagnetic reactions on the circuit under test, which result in the setting up in both circuits of co-existing independent oscillations having periods differing from the periods of either circuit separately. Nevertheless, Wien found in the course of his experiments that there was practically only one oscillation present in the resonant circuit and that this oscillation possessed the unaltered natural period of the resonator. This fact led him to the conclusion that the circuit under test acts only for a very brief period on the resonant circuit, that its action must be in fact a short-lived electromagnetic impulse, that this impulse from the primary circuit endures only while the discharge is in progress, and that when this has finished the primary circuit opens and the secondary resonating circuit continues to oscillate freely in its own natural period unaffected by the now open primary circuit.

The whole process may be pictured thus (Fig. 1) :—

When the discharge-gap G shunted by an inductance L and a capacity C is switched on to the supply circuit, the capacity C becomes charged up until the potential difference at G attains a value sufficient

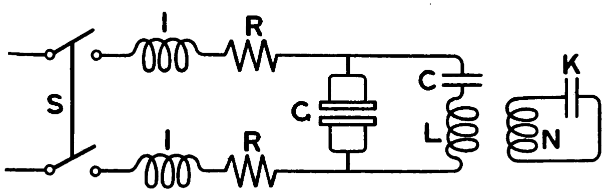

FIG. 1.

to break down the gap. A discharge then takes place across G, and continues in virtue of the electrical inertia of L until C is more than discharged, and in fact becomes charged oppositely. If an arc becomes established at G, a series of charges and discharges of decreasing amplitude may occur, but if the arc due to the first discharge of C dies out at the moment of reversal of the current, then the oscillations in the primary circuit will not take place, with the result that the resonating circuit NK is only affected by the action of the primary as by a quick blow. Such blows will evidently occur at intervals of time whose length depends on the size of the condenser C and of the choking coils I. It is to be expected that the arc will be quenched the more effectively the stronger the cooling to which it is exposed. Whatever method of cooling the discharge path be adopted the carrying away of the heat will be facilitated by reducing the gap between the electrodes and so displacing gas, which is a poor conductor of heat. Hence when short gaps are used, efficient cooling and rapid quenching of the discharge will be effected. Of course, when long gaps are used the gas heated by the discharge can be removed bodily

from between the electrodes by a blast of air or other suitable gas, and a gap so operated yields the quenched discharge phenomena well; but the method of the short gap, wherein the heat is abstracted from the gas through the mass of the electrodes, is said to be less wasteful than the method in which the heated gas is removed by a blast. Whichever method be used, it is an obvious advantage to arrange that the electrodes themselves are well cooled, for instance by making them hollow and passing cold water through them. By this means the formation of an arc even in the first phase of the discharge is rendered more difficult, for, if the metal be kept cold, its evaporation into the path of the discharge will be diminished and the formation of a true arc (*i.e.*, discharge through vapour of the material of which the

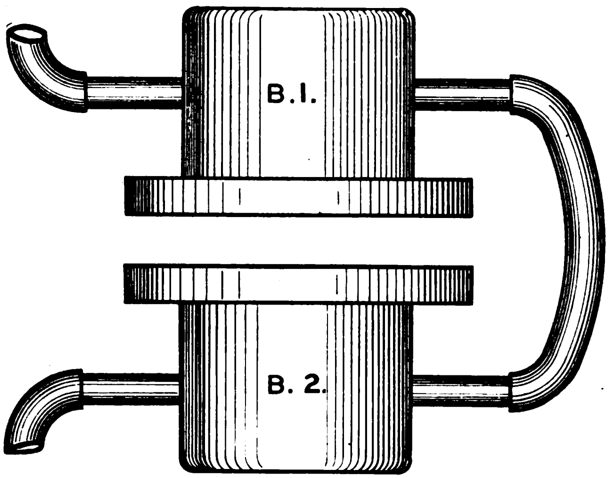

FIG. 2.

electrodes are composed) will be hindered. Thus when the current falls to zero the discharge will have difficulty in continuing.

All the above considerations enter into the operation of the form of discharger used especially by von Lepel for generating high-frequency oscillations for wireless telegraphy, and with a view of investigating the efficiency of such a method the following apparatus was used by us. Fig. 2 shows the discharger, consisting of two parallel surfaced copper plates between which the discharge passes and which form the opposed faces of the metal boxes B_1, B_2. These boxes are supplied with flowing water by means of rubber pipes, the same water flowing through the boxes in succession. The discharge surfaces are kept at the correct distance apart by means of one or two paper rings, the thickness of which has to be chosen to suit the supply voltage and the current flowing. One or two thicknesses of foreign note proved to be

suitable for our experiments. Connection to the rest of the circuit was made by soldering leads to the boxes.

For the purposes of wireless signalling the discharger just described is connected as shown in Fig. 3, in which I I represent choking coils, R R regulating resistances, and S the main switch in the supply leads. The primary oscillating circuit is formed by the inductance L and the capacity C, and the secondary circuit by the aerial conductor whose capacity to earth is K, the inductances N and L, and the condenser C. The last-named path must be tuned by trial to the oscillating circuit L G C. It will be noted that the secondary is associated with the primary firstly by the direct or conductive coupling at G, and secondly by the mutual inductance coupling between N and L. The two couplings must be connected so as to conspire.

It is evident that, if much energy is to be delivered from the mains to the primary condenser, this condenser must be of considerable

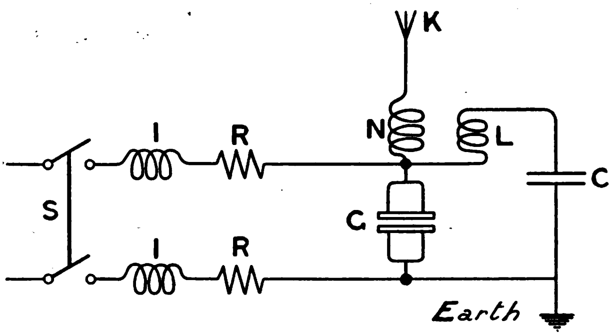

FIG. 3.

capacity, for the potential difference at the supply terminals is usually of the order of 500 volts, which is very low according to the usual practice in other methods of wireless telegraphy. A large condenser also favours the working of this method by furnishing at the moment of its discharge a reverse current of sufficient magnitude to cancel the main current in the gap and thus accomplish the extinction of the arc.

If we consider the factors entering into the efficiency of the system, we see that only a fraction of the total energy taken from the supply circuit is received at the gap terminals, and that only a fraction of this again will be received into the secondary circuit or aerial. Of this last portion some will be wasted ohmically, but most will be radiated.

The overall efficiency of the process is obtained by dividing the energy radiated by the energy taken from the direct-current mains. This figure has in the best case a very low value owing to the large proportion of the total energy that has to be wasted in the ballast resistance R. Another figure for the efficiency which is often given takes no account of the losses in the resistance and is obtained by

dividing the energy radiated by the energy supplied at the gap terminals, and thus includes among the losses only the heat generated at the gap and in the oscillatory circuits.

Inasmuch as there is no direct way of measuring the energy radiated from an aerial wire, we used in our experiments a special resistance instead of an aerial for dissipating the energy. It is known that the energy dissipated by an average aerial can be represented quantitatively by the heat generated in a series resistance of 30 to 60 ohms. Our resistance possessed a high-frequency value of nearly 40 ohms; it was connected in the secondary circuit as shown in Fig. 4 at *r*. The capacity of the aerial was at the same time replaced by an air condenser K of capacity about the same order as that of an actual aerial consisting of alternate sheets of zinc forming one pole and of plate glass coated on one side with tin foil forming the other pole. The sheets stood on edge and rested on ebonite supports and had each an area of 18 in. × 11 in. The distance between the active surfaces was about 1¼ in., and the capacity could be varied by removing plates of

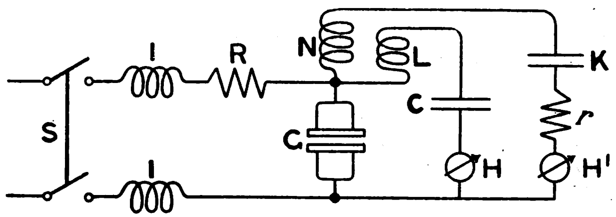

FIG. 4.

zinc wholly or partly. The condenser C consisted of sheets of tin foil of area 10 in. × 10 in. pasted on to the surface of micanite board of thickness 0·01 in. Alternate sheets were connected together and the whole was clamped tightly together in a wooden press. The capacity could be varied by using different numbers of sheets by making suitable connections between the terminals brought out. H and H′ are hot-wire ammeters used merely as indicators. The resistance *r* was placed in a small calorimeter containing paraffin oil and provided with a stirrer and delicate thermometer. The ballast resistance R in the main circuit consisted of No. 30 bare Eureka wire wound on a wooden frame, the whole being placed in a calorimeter containing paraffin oil. The resistance was varied by soldering leads to different places along the wire. The calorimeters enabled the energy passed on to the secondary circuit as electrical oscillations and the heat wasted in the ballast resistance to be measured simultaneously. For determining the heat wasted in the arc advantage was taken of the cooling system. Water at a steady inflow temperature was passed from a tank through the box electrodes into glass measuring vessels. The difference between the temperature of the water in the tank and that

of the warm water collected in the measuring vessels furnished a tolerably good estimate of the heat wasted at the gap. The rise of temperature in the cooling water and in the calorimeter in the secondary circuit was never more than 13° C., so that the radiation losses could be ignored. The thermometers used were graduated in tenths of degrees C.

The programme followed in a typical experiment was as follows: The initial temperatures of the calorimeters and of the cooling water were read and recorded, the water was turned on and then the main circuit switched on. The hot-wire ammeters showed whether the oscillations were of normal strength. When the thermometers in the calorimeters, kept duly stirred, showed a suitable rise of temperature the current was switched off. The calorimeters were further stirred until the temperatures became steady and the thermometer readings recorded and in the meantime the temperatures of the successively filled measuring vessels collecting the cooling water were recorded until the water showed no rise of temperature above that of the tank. The water equivalent of each calorimeter and contents was determined before and after the whole set of experiments by measuring the weights of the copper and of the oil. The electrical dimensions of the apparatus were:—

$L = 8{\cdot}0$ microhenries. $N = 171$ microhenries.
$C = 0{\cdot}041$ microfarad. $K = 0{\cdot}0019$ microfarad.

r had a high-frequency value of 38 ohms and a negligible inductance. R was given different values and so controlled the current through the arc. The supply voltage was 500 volts. The frequency of the oscillations was 294,000 cycles a second, and therefore the wave-length was 1,020 meters.

The results of some of the experiments are set out in the table:—

Short-circuit Current.	Current during Run.	η.	η'.
1·46	0·7 to 0·9	0·489	0·144
1·46	0·8 to 1·0	0·373	0·120
1·87	—	0·446	—
2·10	1·4	0·406	0·055
4·70	3·4	0·357	0·046
6·75	—	0·186	0·012

The short-circuit currents shown above were the currents that were

found to flow when the line voltage was applied to the circuit with the gap shorted.

η represents the efficiency exclusive of the losses in the ballast resistance.

η' represents the efficiency including the losses in the ballast resistance.

The method of calculating the efficiency will be best explained by taking a numerical instance.

The efficiency for the case when the short-circuited current was 4·7 is obtained as follows :—

Calorimeter containing ballast resistance R.
Water equivalent, 1,630 grammes.
Initial temperature, 33° C. Final temperature, 45·5° C.
Temperature rise, 12·5° C.
Heat units, 1,630 × 12·5 = 20,400 gramme-calories.
Calorimeter in secondary circuit containing resistance *r*.
Water equivalent, 295 grammes.
Initial temperature, 20·7° C. Final temperature, 24·23° C.
Temperature rise, 3·57° C.
Heat units, 295 × 3·57 = 1,065 gramme-calories.
Water warmed by the arc.
Initial temperature, 17·2° C.
Water equivalent of measuring vessel filled with water, 600 grammes.
Temperature of water (collected at successive fillings), 18·95° 18·20°, 17·55°, 17·30°, 17·20° C.
Temperature rise, 1·75°, 1·0°, 0·35°, 0·10°.
Heat units, 600 (1·75 + 1·0 + 0·35 + 0·1) = 600 × 3·2 = 1,920 gramme-calories.

Hence we obtain—

$$\text{Efficiency } \eta = \frac{1065}{1920 + 1065} = \frac{1065}{2985} = 0·357$$

$$\eta' = \frac{1065}{20400 + 1920 + 1065} = \frac{1065}{23385} = 0·0457.$$

(Appears as 0·046 in table.)

The highest overall efficiency recorded above is 14·4 per cent.; and this was the highest efficiency reached in all our experiments. The values for the overall efficiency become lower the greater the current. This is perhaps due to the difficulty that is experienced in keeping the arc in an active condition throughout a run, a difficulty which becomes greater the greater the current that is flowing. It would seem that there were two kinds of discharge : one producing oscillations and the other not being active in that way—the former being obtained when

the electrodes are thoroughly cool, the other when they become heated. Obviously the latter is more likely to occur when the current is heavy, and hence the overall efficiency falls in value as the currents are increased, since the heating in the calorimeter in the supply circuit continues at an increased rate during the time when the gap has become temporarily short-circuited and in consequence inactive.

This source of error was minimised in all our experiments by watching the hot-wire ammeters and rotating one of the electrodes relatively to the other as soon as the oscillations showed signs of dying out.

In actual practice, when the oscillations are being used for wireless signalling, the discharge is broken up into dots and dashes and so the heating of the electrodes may be so much less than in our continuous runs that somewhat higher values of the efficiency may be obtained momentarily.

It has been stated that overall efficiencies of 60 per cent. have been obtained, but the above measurements cast some doubt on the rough estimates published hitherto.

Discussion.

Mr. Taylor.

Mr. J. E. Taylor: It is of considerable importance to engineers who are engaged in wireless telegraphy to know just how to make such measurements as Professor Fleming has been explaining to us. In connection with the method of measuring the high-frequency resistances of conductors Professor Fleming does not tell us what percentage of accuracy is possible. Presumably it is not very high as yet. We all know the difficulties that are experienced in attempting to make measurements where we have to keep the sparking rate constant, so as to keep the current uniform; where we have to keep the spark-gap in adjustment, or adopt means to keep it constant; and where we have to integrate the effect over a considerable period. On looking at the table to find how far this is an accurate method, I cannot help feeling a little disappointed. In the table opposite page 352 are two successive measurements for bare copper wire No. 14, one taken at a frequency of 470,000, and the other at a frequency of 440,000. The result of the measurement is that the higher frequency gives the lower resistance, which, of course, is not consistent with the calculated values. In the second measurement both high-frequency resistances are made to have the same value, but the frequencies concerned are not very different. In the next test the discrepancy is rather greater. The frequency is 540,000 in the first case, and the high-frequency resistance is equal to the steady current resistance; and in the second case it is 736,000, and the high-frequency resistance is smaller than the steady current resistance. In most of the other results similar remarks apply. I am afraid that means that the method of checking the losses throughout a wireless telegraph installation of the type shown is not a very accurate one, and I am rather inclined to doubt the accuracy of the figure ultimately arrived at as the amount of

energy radiated from the antenna at University College, namely, 78 watts when originally excited with 2,620 watts imparted to the rotary transformer. A still stronger reason for doubting its accuracy is that on page 381 the high-frequency resistances of the antenna circuit are given as 0·528 ohm for jigger secondary circuit, and 0·21 ohm only for the antenna proper. The figure of 0·21 ohm may be correct so far as the copper losses in the antenna are concerned, but surely it takes no account of the losses in another important part of the oscillating system which is combined with the antenna, namely, the earth. We must not forget that the current has to leave the root of the antenna and spread over the surface of the earth; and I cannot help thinking that in whatever way the earth connection is made, there must be considerable losses on this account. The latter would depend upon the specific high-frequency resistance of the soil. We have other losses due to the electrostatic induction on neighbouring conductors or semi-conducting masses such as the walls of the building, other conducting pipes, or wires in the building, in all of which oscillating currents are induced, increasing the total losses. We have also electromagnetic induction giving rise to similar sources of loss. In other words, the condenser losses of the antenna appear to have been overlooked, so that the amount of loss in the antenna is really greater than is shown in the table, and the actual balance available for radiation is considerably smaller. Mr. Taylor.

Professor E. WILSON: I may say that in connection with the system of radio-telegraphy in operation between University and King's Colleges, I have had some experience with the apparatus which has been shown here to-night by Dr. Fleming, and the ease with which it can be tuned and operated in practice is beyond all praise. One important point which has been dealt with in these papers is what may be termed energy efficiency. Apart from the scientific importance of the subject, I think it is the duty of all engineers, when they have systems in their charge, to allocate the losses in those systems as far as possible, and to find out what they amount to. Another point which I should like to raise is the question of the granting of licences by the Post Office. It seems to me that the granting of licences to those who use radio-telegraphic installations should rest upon the rate at which energy has to be given to the ether itself, and not upon the rate at which it has to be given to the translating devices. I think the Post Office engineers will appreciate these papers, because they will be enabled to form some estimate of the rate at which energy has to be given to the ether by the antenna in order to operate over a certain distance, and so on. We are all of us familiar with what is termed the Board of Trade Panel in Electric Traction Systems, and I have visions of what may be termed a Post Office Panel in Radio-telegraphy Systems. We may presently find that all our deeds are recorded upon paper, so that if we overstep the mark and put energy into the ether at too great a rate we shall be found out by the Post Office. Professor Wilson.

I should also like to refer to the subject of eddy currents. Those

Professor Wilson.

who have been in a large alternating-current power station may have noticed a phenomenon which is at first sight a little puzzling. In the case of a busbar consisting of three parallel copper conductors in the same plane and pooled together at their ends, when alternating currents are flowing through the busbar, the outer conductors become warmer than the inner one. The self-induction effects in the bars are dissimilar, and the outer bars are compelled to carry more current than the inner one. In the same way it seems to me that in the case of an antenna consisting of more than two elevated conductors in a plane, the outer conductors may be carrying currents which are considerably greater than the inner ones. If that be so, the total dissipation of energy in that antenna will differ from the energy as calculated from the experiment in Fig. 3 of Dr. Fleming's paper. Another point in connection with Fig. 3 is the inductive action of the oscillating current wire upon the wire carrying the direct currents. This should be negligible. Referring again to the alternating-current experiment, if a plate be substituted, the effects will be similar. Therefore the distribution of electric current over such a plate will not be uniform. In the condenser plates shown in Fig. 5, the current enters at a given point, and the assumption is that it distributes itself uniformly over the surface of the plates, producing a constant inductive effect per unit area. I quite agree with Dr. Fleming that by the use of such a substance as paraffin oil which obeys Maxwell's law with regard to the refractive index, the residual charge effects in such a condenser will probably be negligible; but I am not quite sure about the smallness of the dissipation of energy in those condenser plates when they are traversed by these high-frequency currents. The distribution of the charge on the plate itself will not be uniform, and this will affect capacity. Therefore it seems to me that there may be one or two matters which, when looked into, affect the figure of 78 watts, which Dr. Fleming has arrived at on page 382.

Professor Morris.

Professor J. T. MORRIS: The papers which we have just heard are, in my estimation, both of a pioneering character. It would be interesting to know whether the authors have made experiments on the variation of efficiency with length of spark. In connection with this subject, the curves shown in Fig. A may be of interest. These give the results of certain experiments made two years ago by myself and Mr. A. G. Warren at the East London College. The results shown in these curves were obtained by using in the case of air a Hertz oscillator with 1-in. brass balls, and in the case of liquids the Langwitz aluminium pencils oscillator with a micrometer adjustment. The induction coil used was fitted with a motor-driven mercury-jet break working in coal gas. The receiver, placed about 10 metres away, consisted of two straight wires 160 cm. long with a Duddell thermo-galvanometer of 355 ohms bridging the gap. The "air" curves give the variation in current received when the sparking distance at the oscillator was varied from 0 cm. up to 1 cm., the maximum effect being obtained with a 4 mm. spark.

Professor Morris.

Further, I should like to know if the authors have examined the changes in the efficiency due to variation of the medium in which the spark occurs. In this connection Figs. B, C, and D (reproduced from a paper read by myself before the British Association, 1907)* illustrate the differing effect produced on alternating-current arcs working at

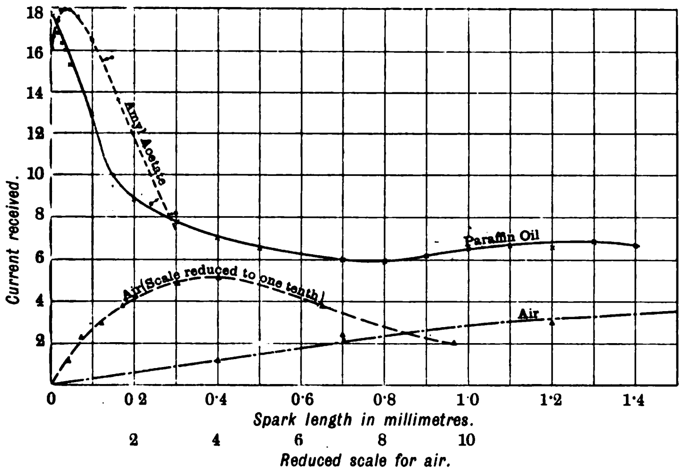

FIG. A.

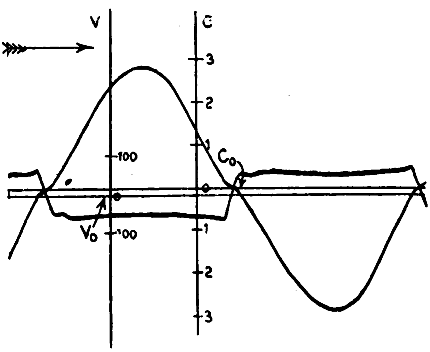

FIG. B.—1 mm., Arc in Air.

a frequency of 60 cycles per second in air, coal gas, and liquid amyl-acetate. The ampere-wave has been reversed in all cases to avoid confusion. The arcs in each case were working off a 400-volt circuit and carrying about 2 amperes. I would point out that in the case of coal gas and amyl-acetate the voltage rises to 300 or 400 volts before the arc-current flows, whereas in the case of air 70 or 80 volts

* *Electrician*, vol. 59, p. 707, 1907.

Professor Morris.

suffice. No doubt there is a vast difference between operating with arcs at a frequency of 60 and sparks at a frequency of half a million. Referring again to Fig. A, the curves there given illustrate the effect on the intensity of the current received (on the thermo-galvanometer in the receiving circuit) of varying the length of the transmitter spark in the case of air, paraffin oil, and amyl-acetate. It appears

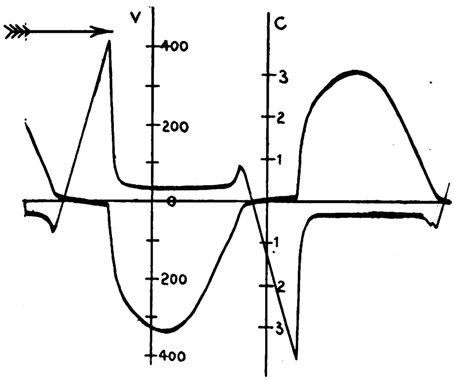

FIG. C.—1 mm. Arc in Coal Gas.

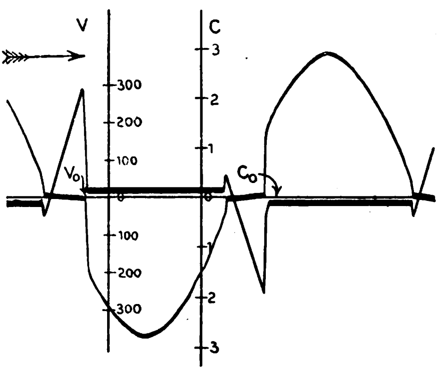

FIG. D.—0·5 mm. Arc in Amyl-Acetate.

that when paraffin oil is used, about thirteen times the energy is received as compared with air, whilst with amyl-acetate a similar result is obtained. The most efficient length of gap came out as follows :—

Air	4·0	millimetres.
Amyl-acetate	0·040	„
Paraffin oil	0·004	„

Dr. Erskine-Murray.

Dr. J. ERSKINE-MURRAY: I think all of us will agree that the most novel part of Professor Fleming's apparatus is the differential thermo-ammeter used for measuring resistances. There are two sources of error which Dr. Fleming apparently has not noticed, or possibly has not thought worthy of mention. As, however, they involve a gain or loss of 2 or 3 per cent., I may as well point them out. The first cause of error is that the induction coil is coupled directly to the left-hand side of the apparatus, the result being that the wire W_1, which is used for the high-frequency current, has temporary unidirectional current travelling through it at the commencement of every train of waves during the charging of the condenser. Then comes the discharge. *i.e.*, the train of waves, and that, of course, is of high frequency. The difference between the observed and true resistances ought to be from 5 to 10 per cent., depending upon the ratio of the duration of the charging current to the duration of the train of waves. If the train of waves is very much damped, the charging current will produce a large proportion of the total heat, and an error in the value of the high-tension resistance will result. Then there is another source of error which, luckily for the experimental results obtained, may somewhat counterbalance the former one. Dr. Fleming does not seem to have included any correction for the fact that the waves are damped, which would make the resistance of the wire higher for damped than for undamped waves, to which latter Lord Rayleigh's formula applies. Dr. Barton has given the equation for the value of R for damped currents, and I find by working out his figures on the assumption that the damping of the circuit is 0·1, that the resistance should be about 4 per cent. higher than that given by the formula used by Dr. Fleming. This 4 per cent. difference is in the opposite direction to the other correction, and therefore the two errors may in part cancel one another. The photographic recorder is a very interesting piece of apparatus, but the photographs are not nearly so beautiful as those taken on a cinematograph recorder with steadily moving film, shown in Ruhmer's book on wireless telephony. The latter show the increased number of sparks obtainable by varying the constants of the oscillating circuit, *e.g.*, the resistances in series and the capacity. Professor Majorana and M. Blondel have attempted to obtain a very high spark rate from alternating-current supply for the purposes of wireless telephony by using an almost rectangular wave-form, and though a very large number of sparks were obtained from each alternation the method was not successful on account of the recurrent blanks at the moments of zero voltage. With regard to the hammer break, I wonder whether it is possible that the long series of sparks at each interruption, when the spark-gap is small, may be partly due to the oscillations of the primary circuit; because with the hammer break one always uses a large condenser, a primary with inductance, and a not too tremendous damping, so that in all probability the secondary sparks would follow one after the other on the maxima of the primary circuit current. That is a possibility which may occur; I do not know what Professor Fleming thinks about it.

Dr. Erskine-Murray. As regards Dr. Eccles' and Mr. Makower's paper, it is pleasing to see that they have obtained as high an efficiency as 14·4 per cent. If we compare it with 10 per cent. found for Dr. Fleming's spark station, it shows that this method is an advance upon the spark method. They obtained this 14·4 overall efficiency in spite of a number of things which perhaps greater experience with the apparatus would have taught them to avoid. First of all, in the diagram the regulating resistances are shown between the choking coil and the generator. Therefore, the high-frequency energy must go back through those regulating resistances as far as the choking coil, and there must be some loss there. Then, although they used direct current, both the electrodes were made of copper. It is certainly more efficient to use one electrode made, say, of brass or delta metal and the other of copper. What they say as regards the condenser is obviously right, that in order to get high-energy and good efficiency its capacity must be great. But the condenser they use is not nearly so large, as far as I am aware, as that in actual use in other systems. I am not quite certain what is done in the Telefunken system, but the Lepel condenser is fully ten times as large as the author's condenser.

Again, there are two circuits shown in Fig. 4, but there does not appear to be any inductance to correspond with the inductance of the aerial; where does this come in? Then there is an ammeter in the main circuit, and unless this is of extremely low resistance or has a low resistance shunt, it may well reduce the efficiency. Another point is that they use Eureka wire for the regulating resistances, that is, a wire which has practically no temperature coefficient. It seems to me that this is the very worst wire they could possibly have used. What is wanted is a wire which has the highest possible temperature coefficient, and which is cooled in the most efficient manner, in order to check the increase of supply current, so that the discharge will only be an impulsive rush in one direction, and will be checked off at once through the limitation of the supply current by the resistances. A very fine iron wire heats up so rapidly and cools so rapidly as the current changes that it is actually capable of following these very rapid changes. The result is that the Eureka would allow a large rush of current to come just at the wrong moment, when the spark ought to be cooling off, whereas with an iron wire, when the current is increasing the resistances increase, and therefore the current is checked so that there is no further rush. As to the figure of 38 ohms which the authors give as the value of the aerial damping, it may be, as they say, anything between 30 and 60 ohms. I have not looked exactly to see how that affects the final efficiency result, but surely a difference between 30 and 60 ohms would make a serious difference in the efficiency obtained. On its own merits, in spite of the weaknesses in design indicated above, the paper is a most interesting and valuable contribution to our knowledge of the subject.

Mr. Bright. Mr. CHARLES BRIGHT, F.R.S.E. (*communicated*): Dr. Eccles and Mr. Makower have done a good service in drawing attention to the

importance of keeping the electrodes cool when working with short spark-gaps. Where the gap across which the discharge takes place is short only a low potential is required, thereby permitting more current to be used. This arrangement is favourable for the safety of the apparatus and the operators working it; on the other hand, it is liable to cause arcing which, in generating heat, is always a fruitful source of trouble. As the authors of the second paper suggest, it is difficult to say definitely whether the discharge in such case is of the nature of a spark or an arc—or, indeed, to draw a fine line between the two. In any case a considerable amount of heat is evolved. There can be little doubt that the generation of heat between the electrodes tends to affect more or less seriously the constancy of (1) the energy, (2) of the emitted wave, and (3) the efficiency of transformation. Mr. Bright.

Messrs. A. J. MAKOWER and W. H. ECCLES (*communicated*): The point in Professor Fleming's paper of greatest immediate interest to us is his measurement of the high-frequency resistance of straight and coiled wires. Any one who has worked at high-frequency measurements will know that there are at present too many formulæ in general use which are uncorroborated by experiment. Dr. Fleming is doing a great service in remedying this defect. One very valuable conclusion that can be drawn from his experiments is that the high-frequency resistance of a very thin copper wire is undoubtedly the same as the steady current resistance. Of course, this was known before as a matter of theory, but few practical people felt safe in relying upon mere calculation. We realise the importance of Dr. Fleming's work all the more, as we have been working for some time on this very matter; in fact, Dr. Fleming has to a great extent taken the wind out of our sails. Messrs. Makower and Eccles.

We, like Dr. Fleming, used an air thermometer containing the wire under test, but we provided the vessel with a vacuum jacket. The main difficulty that we have encountered has been due to the leakage of heat out of the air chamber along the leading-in wires. This leakage was found to have a very great influence on the final temperature reached by the wire even when we were using thin leading-in wires. We note that Professor Fleming has used thick masses of metal to convey the current to the wire under test, and suggest that the failure of the apparatus to yield results of high accuracy may be largely due to this cause. As it still seems desirable that the formulæ for the high-frequency resistance of wires should be thoroughly confirmed, we propose to continue our experiments in the hope of attaining enhanced accuracy.

Professor G. W. O. HOWE (*communicated*): Professor Fleming mentions the attempts made by Max Wien and Sommerfeld to determine mathematically the effect of frequency on the resistance of coils, and points out the lack of agreement between the formulæ so obtained and the experimental results. He does not refer, however, to the important investigation of Louis Cohen,* who points out that both Professor Howe.

* *Bulletin of the Bureau of Standards*, vol. 4, p. 161, 1907.

Professor Howe.

Wien and Sommerfeld made assumptions which must necessarily lead to a wrong result. He then establishes a formula which he claims to agree very closely with experimental results. He seems, however, to have confined his experiments to comparatively low frequencies, at which his formula is undoubtedly far superior to the others. It would be very interesting to see how Professor Fleming's high-frequency experiments agree with Cohen's formula.

I should like to ask Professor Fleming whether he has tried using continuous oscillations in this experiment instead of intermittent damped trains of waves. An arc generator could be kept constant and continuous enough for a much higher degree of accuracy than one would expect from the spark method employed.

Mr. Davies.

Mr. B. DAVIES (*communicated*): There is a vast amount of valuable material in Dr. Fleming's paper for which radiotelegraph engineers will be grateful. The paragraph on the measurement of spark frequency, though not the most important in the paper, is highly interesting. The great irregularity in the sparks revealed by Dr. Fleming's counter is astonishing. But it is not certain that his results are sufficiently conclusive with regard to the statement made on page 367, viz., that the "spark counter shows us the futility of all plans for effecting resonance between two stations by syntonisation of the spark frequency and not the oscillation frequency." Provided the ionisation difficulty can be avoided (and I think it can with due precaution), and provided also that the spark frequency be not too high, and the relation between the spark-length and the E.M.F. of the charging circuit be so arranged that only two sparks per period are possible, it would seem that the discharge should occur with considerable regularity if the source itself be truly periodic. Under these conditions the spark would encounter the same obstruction at all times.

The calculation and measurement of the inductance of a flat spiral are also interesting, and it is remarkable how close, in certain cases, are the predicted and measured values. There is, however, in this connection a point on which I am not quite clear, namely, the relative inductance values of the two pairs of coils on page 357. Dr. Fleming finds by measurement that the cylinder inductance is greater than the spiral inductance of the same turns and mean radius by about 3·5 per cent., and ascribes the difference "to the fact that the Stefan formula is not symmetrical in b and d." I may be in error, but should not b and d be unsymmetrical? It would seem that the cylinder should possess a greater inductance than the spiral. If the spiral and the cylinder gave the same inductance, it would follow that the cross-section giving the maximum inductance would be a square, which, I think, is not the case. I find by an approximate formula that for the two upper coils in Fig. 7 the cylinder gives 4 per cent. greater inductance than its flat brother of the same number of turns and mean radius. This is a close approximation to the 3·5 per cent. observed by Dr. Fleming.

The efficiency of transmission mentioned at the end of the paper is also interesting. The figures given for the power issued by the sending antenna, and the power caught by the receiving antenna, reveal an enormous attenuation of the strength of the signal with distance. Thus, of the 18,000,000 ergs emitted from the battleship *Henry IV.*, only 320 ergs could be picked up at a distance of 1 kilometre or 0·63 mile. This represents a "power attenuation constant" of 20 per mile. Compared with the same "constant" for submarine cables, this is a very large figure. A cable working at top speed gives a power attenuation of the order of 0·01 per mile. The wireless attenuation is thus 2,000 times as great as that of a submarine cable. This exhibits well the great sensibility of the coherer. Mr. Davies.

Mr. T. L. ECKERSLEY (*communicated*): On page 352 Dr. Fleming describes a hot-wire ammeter for measuring large high-frequency currents, and gives the impression that this is practically the only way to measure large high-frequency currents. I should like to point out another method which I have found to be a very convenient way of measuring these currents. The method is to use a current transformer whose secondary is short-circuited on to some low-resistance thermal detector which can be calibrated with direct current. We have in this case, if I_1 and I_2 are the effective primary and secondary currents, $I_1 = \frac{L_2}{M} I_2$ where L_2 is the secondary self-inductance and M the mutual inductance between primary and secondary. This relation is independent of the frequency and depends only on the constants of the instrument itself. It is rigidly satisfied in two cases— Mr. Eckersley.

1. When the resistance of the secondary is zero.
2. When M is very small and the dampings of the primary and secondary circuits are equal.

In practice, however, R_2, the secondary resistance, can be varied within fairly wide limits without affecting the ratio of I_1 to I_2.

Dr. W. H. ECCLES (*in reply*): Professor Morris asked if we had measured the efficiencies with various lengths of spark-gap. We took papers of a great variety of thickness, used them singly, doubly, trebly, and even quadruply, and picked out the best for each current. As regards the medium between the plates, no doubt it is highly hydrogenous. When paper burns, very complex chemical changes must occur. Poulsen found that the Duddell arc operated with increased vigour when the smoke of burning paper was allowed to pass between the electrodes, so that I have no doubt that in the Lepel method the burning paper helps very greatly in producing energetic oscillations. Dr. Murray made some remarks about the chokers. The resistances in our experiments were really placed between the chokers and the supply mains and not as shown in the diagrams, but an interchange of their positions would not have any effect on the oscillations since there is no reason why the oscillations should have appreciably Dr. Eccles.

Dr. Eccles. different values on the two sides of a choking coil. A difference between the currents on the two sides could only be due to the small electrostatic capacity of the chokers. The wastage of energy due to a capacity current charging the chokers is known to be quite insignificant when you have a tuned secondary circuit coupled very closely with the primary circuit, and when you have in that secondary circuit a means of absorbing energy. It must be remembered that calorimetric measurements are most difficult to make precise. If the calorimeter measurements are true to within 5 per cent. we shall be very glad.

We have purposely inserted in the table on page 392 the second result to compare with the first one in order to show the variation we obtained in our results with similar adjustments on various occasions. It will be noted that we found efficiencies of 37 per cent. and 49 per cent. under exactly similar conditions. It may, however, be remarked that this variation is probably not wholly due to errors in the calorimetric measurements but partly to the difficulty in keeping the oscillations perfectly constant which is referred to at the end of our paper.

With regard to delta metal as against copper, we have not tried it, but have tried two kinds of hard brass without finding any difference.

As regards the absence from the diagram of our dummy aerial of an inductance representing the distributed inductance that exists in an actual aerial, we may point out that this is included in N of the diagram. As a matter of fact, in the experiments we had an inductance additional to that of the secondary of the oscillation transformer since this was not large enough alone.

As regards the condenser which Dr. Erskine Murray says is much smaller than that used by Lepel, it was designed after a visit to the Slough station, and is of about the same size as those then in use. The ammeters were shunted, of course; they were used as indicators. With regard to the Eureka wire, I did not follow the argument about the Eureka not stopping surges of current, and that iron wire was far more efficient. I understood Dr. Erskine Murray to say that if iron were used in the calorimeter it would stop surges of current but that Eureka wire would not. This is not correct. Surges were effectively prevented by the insertion of the large choking coils I, and so the composition of the resistance would be immaterial. With regard to the resistance of the aerial, the figure of 40 ohms was arrived at in this way. If you look at page 393 you will see that the calorimeter in the secondary circuit is stated to give 1,065 gramme-calories in about three-quarters of a minute. That gives a rate of radiation of about 100 watts. We took 100 watts as being what is usually radiated from an aerial. We know that a similar figure for the resistance has been arrived at by observers in many countries. In our own country, for instance, Messrs. Duddell and Taylor measured the radiation resistance of an aerial, and it came out, I think, at 56 ohms. An alteration of this resistance in our experiments would certainly alter the energy con-

sumption in the secondary circuit, but need not alter the efficiency of the transformation as Dr. Murray seems to imply. Dr. Eccles.

Dr. Fleming. Dr. J. A. FLEMING (*in reply, communicated*): In the table giving the results of measurements of high-frequency resistance as printed in Table I. in the proof circulated before the meeting there were undoubtedly discrepancies due either to some little miscalculations or copying out results and partly to errors of observation, to some of which Mr. Taylor has drawn attention. The method described for obtaining the high-frequency resistance is one which certainly requires care to obtain a high degree of accuracy, and I did not in the paper lay claim to any particular percentage of accuracy simply because I knew that there are many difficulties in the measurement not yet entirely overcome. With care, however, I think that an accuracy of 1 per cent. can be obtained.

Since the paper was read, Mr. Dyke has repeated for me with very great care the measurements for the ratio R′/R in the case of the Nos. 14, 16, and 36 copper wires, and the results now given in the finally corrected Table show a close accordance with the predictions of theory, the discrepancy to which Mr. Taylor drew attention in the case of this wire having disappeared.

The measured ratio R′/R increases with the frequency as it should do. As a further check on the accuracy we have tested a No. 40 S.W.G. copper wire, and found in that case that the ratio R′/R is unity as theory predicts. This kind of resistance measurement is, however, quite new, and was undertaken in the first place with the object of testing the general accuracy of theoretical predictions, and the chief result of value which has come out of it is the guidance it has given in showing us how to design a high-frequency ammeter.

Dr. Erskine-Murray has made two criticisms which must be noticed. He thinks that I have neglected to take account of the heat produced by the low-frequency charging current of the condensers which passes through the wire under test, and also of the increased heat produced by damped oscillations, though the calculated resistance is determined by a formula which presupposes undamped oscillations. These criticisms are qualitatively correct, but quantitatively they are invalid for the following reasons. The charging current of the condensers is a low-frequency current (about 50 $\sim$), and in the case of the tests with the No. 14 wire this charging current, as measured by a hot-wire ammeter, was found to be only 0·06 ampere, whereas the oscillatory current was 6·2 amperes. Moreover, the low-frequency current only operates on the low-frequency resistance of the wire whilst the high-frequency current operates on a high-frequency resistance more than six times as great. Hence the ratio of the heat produced by the charging current to that produced by the oscillations is as $(0{\cdot}06)^2 \times 1$ to $6^2 \times 6$, or as 1 : 60,000. Accordingly the error from this cause is negligible. Again, as regards the difference between damped and undamped high-frequency resistance. Dr. Barton shows* that

* *Philosophical Magazine*, vol. 47, p. 437, 1899.

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the correcting factor is equivalent to $s\sqrt{s+k}$ where $s=\sqrt{1+k^2}$ and $k=\delta/\pi$, δ being the decrement per semi-period. Now, in my experiments the spark-gap was kept as small as possible to keep down the decrement, and measurement showed that δ had a value of not far from 0·04. Hence $k=0{\cdot}013$ and $s\sqrt{s+k}=1{\cdot}007$.

In other words, the correcting factor in this case is 0·7 per cent. and not 4 per cent. as Dr. Erskine-Murray states. In all other cases the above corrections did not amount to 1 per cent., and as I made no claim for a higher accuracy it did not seem worth while to introduce these corrections.

One of the practical difficulties connected with the apparatus has been mentioned by Mr. Makower and Dr. Eccles, viz., the conduction out of, or into, the supports or terminals carrying the wires. If these supports are made massive they conduct some heat out of the wires under test. If they are made thin they have heat generated in them and give it up to the wires under test. One must have either the one or the other. I think, however, that the error from this source is not very serious. Our object is to find the ratio of the currents which bring the two equal wires to the same temperature, and if they are losing heat at equal rates by conduction to similar supports similarly situated as well as equally by radiation and connection, the equality in the air pressures in the two tubes as read by the manometer will still indicate equality in temperature.

The next point which has been raised has reference to the efficiency measurements in the case of the wireless telegraph plant. Mr. Taylor has stated that the radiation from the antenna is probably less than 78 watts because account has not been taken of the loss in the earth connection. I am not prepared to contend that there is no validity at all in this objection, and in some cases it will certainly be necessary to take it into account. In the case of my transmitter the "earth" is partly a balancing capacity or counterpoise consisting of a very large sheet of zinc, and as the antenna current at the base is small, not exceeding 5 amperes, I do not think that a sensible part of the power given to the antenna is dissipated in the counterpoise.

The total loss in the antenna and jigger circuit is only 16 watts, and the total high-frequency resistance of the counterpoise is far less than that of the antenna. As a general rule, however, the loss from this source can easily be estimated by bending down the antenna itself, so as to form it into a nearly closed circuit, thus eliminating nearly all radiation. If, then, the capacity by proximity to the ground or variation of length of the antenna is adjusted so that the current into the earth is the same as before, the true radiation will be eliminated, and the remaining losses, if any, can still be determined by difference.

As regards the spark counter, Dr. Erskine-Murray thinks the results are not so beautiful as some records of multiple sparks given in Ruhmer's book on "Wireless Telephony" taken on a cinematograph film. On referring to that book (pp. 112–115, Erskine-Murray's English translation), it will be seen that Ruhmer's photographs are of

Dr. Fleming.

sparks which are long thready sparks, like those of an ordinary induction coil, and are not condenser discharge sparks at all. Moreover, the reproductions of my negatives, as given in the proof of the paper, do not do justice to the original negatives, which reveal a wealth of detail not visible in the process block equivalent.

My apparatus is intended to enable an observer to *count* sparks, and for this reason there must be the means of recording time, and nothing of this nature is shown in connection with Ruhmer's photographs. As regards Dr. Erskine-Murray's suggestion that the long train of sparks at each interruption of the primary of the induction coil when a hammer break and short spark-gap is used may be due to oscillations in the primary circuit, I think this is hardly likely to be the case. The capacity and inductance in the primary circuit of the induction coil are, roughly speaking, about 1 microfarad capacity and 0·01 henry inductance, but this primary inductance is uncertain, because it will be reduced greatly by the reaction of the secondary circuit. In any case, I think the frequency of the oscillations in the primary circuit is much greater than the spark frequency found in the photographs.

Another question which requires reply is a query made by Mr. Round in connection with a method suggested in the paper for determining the decrements of the oscillations in the receiving antenna. Mr. Round appears to contemplate the case in which the frequency of the arriving waves is different from that of the receiving antenna, and in this case, of course, the oscillation set up in the antenna is a combination of forced and free oscillations as he states. I, however, assumed that the receiving antenna was tuned to the frequency of the incident waves, and that the associated or absorbing circuit of the receiving arrangement which is inductively coupled to the receiving antenna can then be used to determine the decrement of the oscillations in the antenna.

This can be done by the method I describe. If, however, the antenna itself is out of tune with the incident waves it will need some skill to disentangle the results so as to obtain the required decrement. I am glad to hear Mr. Round has used my second method with success.

Professor Howe calls attention to the discrepancies which still exist between formulæ which have been given for the high-frequency resistance of spirals.

I am well acquainted with the paper of Cohen in the publications of the Washington Bureau of Standards. The frequencies employed by Cohen are in the neighbourhood of 2,000 to 4,000, and far below radiotelegraphic frequencies. I have found a better agreement between the results of observation and Cohen's formulæ than in other cases, but in spite of all the work that has been done, there is still much work for the experimentalist and mathematician before the problem of spiral resistance can be said to be completely solved.

In connection with these experiments on high-frequency resistance and formulæ for it, there is one important matter to which no speaker has referred, viz., the effect of temperature in altering the ratio of

Dr. Fleming.

R′/R. As the high-frequency current heats the wire it increases the resistivity, and so affects the value of $\sqrt{h}$ and of R′/R. This ratio therefore decreases as temperature increases. As the actual measurement is made when the wire is hot it is necessary to take account of the increase of resistance with temperature. For this reason, in revising the figures given in the table, I have taken the resistivity of copper as 1,700.

In conclusion, I may perhaps say that I am glad to find no very great discrepancy between the results obtained by Dr. Eccles and Mr. Makower for the efficiency of the radiotelegraphic transmitter with which they have carried out their experiments and the results obtained by me with a spark transmitter.

I have long been sure that exaggerated claims for radiation efficiency were being made for certain types of arc transmitter, and it is satisfactory in one sense to know that there is probably very little difference between the radiative efficiency of the two types. On the other hand, it is well worth noting, as Mr. Marconi has done in his recent Nobel Prize Lecture, that simply as regards radiative efficiency the original plain self-excited Marconi antenna is as good or better than more recent types. In spite of the criticisms made, however, I think the methods explained by me in the paper you have done me the honour to discuss will be of assistance in enabling us to analyse and evaluate better from a scientific point of view the relative advantages of various forms of radiotelegraphic apparatus.

The President.

The PRESIDENT: I ask you now to pass a hearty vote of thanks to the authors for these two excellent papers.

The resolution of thanks was carried with acclamation.

The meeting adjourned at 9.45 p.m.

TELEPHONES.

By L. E. Wilson.

(*Paper received from the* Manchester Local Section, *October* 16, *and read at Manchester on November* 16, 1909.)

No more interesting subject for a paper can be designed than the development of the telephone industry in this country. Several articles of a technical nature have already been read before the Institution, and it is thought that one of a general character may be useful in showing how much the conditions have changed during the past few years, and also give rise to a discussion in which members generally, as users of telephones, may take part.

In the early days only a few of the large business concerns made use of the telephone service, but nowadays the necessity for telephone service has spread so that every class of the community uses it, and every day finds the telephone supplanting more and more letters, telegrams, and other means of communication.

Twenty-one years ago, when Manchester was not connected telephonically with London, and pioneers were busy anticipating the difficulties of communication owing to the process of inter-switching, etc., there were 1,400 subscribers here and about 5,000 subscribers in the Metropolis. A night service was inaugurated in London about this time, but with indifferent success, and from 10 o'clock at night until 6 o'clock in the morning there were only 40 calls per week, and it was estimated that each one cost 10s. Now at the present time some 18,600 calls are originated on the National Telephone Company's system in London nightly, between 8 p.m. and 8 a.m., and the 103,287 exchange stations as at January 1st this year originate 590,000 calls per day. In Manchester the number of exchange stations have increased to 20,000, giving 138,000 calls per day.

I will not attempt to describe the study and methods involved in constructing and reconstructing a telephone exchange, but will proceed with the commercial considerations connected with the handling of calls. All will recognise that speed is essentially the telephone engineer's maxim, and a few seconds saved on each call approaches gigantic proportions in the aggregate; consequently even the expressions employed by the operators are regulated, and co-operation, or team-work as it is called, is now used extensively, and reacts favourably on the service. An example of the wastage in words, no doubt fresh in the memory of not a few, existed in the local custom of saying "Right" after repeating a demand for a number. When this practice was discontinued the improvement was soon appreciated, as the saving

effected by omitting 100,000 unnecessary words per day is not the only feature involved.

In spite of the strides made, full advantage is not yet taken by the public of all the facilities a telephone service offers, and this is not due to any technical difficulties. In some quarters discrimination is exercised as to the nature of the business involved before the telephone conversation is permitted, with the erroneous idea of reserving the telephone for more important business. The policy of preventing people reaching a correspondent quickly and freely is no more justified than leaving an accumulation of letters unopened and unanswered. It happens, however, that this indispensable means of communication is not only starved and undeveloped, but occasions much annoyance. A tendency to stagnation and disregard is very noticeable in other respects, but improvements are making headway, although the educational process is a very slow one.

The telephone service is the most rapid, cheapest, and most direct channel for information, and this channel should be open both ways, and the intelligent study of the best method of handling telephone calls is of wide importance; as a rule the subscriber is only alive to the delay *he* actually experiences, and is not interested in any irregularity occasioned by his own methods. It is very unlikely that any business concern would willingly carry out work of an unproductive and ineffective character, and yet a large percentage of calls are rendered so through many preventable causes. One of the characteristics in Manchester telephone traffic is the sudden stoppage of work for lunch. Many business houses practically suspend business or even close their doors during this period. The subscriber in London, not aware of this peculiarity, attempts to effect communication at the time, only to be told "No reply," and it may also be remarked that the interruption to business every Whit-week in Manchester is telephonically a calamity. The difficulty in catering for the spasmodic traffic of this description is very great, and considerable foresight is necessary to regulate properly the operating staff's duties to meet the demand.

The "engaged number" question is open to great misunderstanding, and a glance at a characteristic curve showing the number of calls which have to be dealt with during the various hours of the day will, in a measure, convey the reason.

The rise and fall in calls, as shown by this curve, indicates a tendency to crowd the day's work into about two hours in the morning and about two in the afternoon, and this tendency is more pronounced in exchanges serving strictly business localities. This characteristic explains many engaged numbers, but engaged calls are chiefly caused by an insufficient number of lines. The subscriber is usually only interested in outgoing calls, and for this reason it is difficult to get the inward traffic recognised, although it is not at all in his interests to neglect his inward traffic. The demand during the busy times often concentrates some unfortunate interest round one particular number,

and even with the best of conditions it can happen that two or more operators are testing the same line simultaneously, and as it tests disengaged to each operator, a double connection occurs. In up-to-date switchboards this irregularity is reduced to a minimum.

The "engaged number" provides ineffective work at the exchange on some 23 per cent. of the total number of calls; to the subscriber it means lost time and lost or delayed business.

Probably every telephone user will agree that the efficiency of a telephone system is largely in the hands of the operating staff, and not unusually he imagines that he commands the operator's undivided attention. Although this is not so, it is a curious fact that the average time taken by the operator to answer may actually be less when the operator is busy than when she is very slack, due, no doubt, to the fact that she is naturally more alert when working busily.

Visitors to exchanges invariably ask questions regarding the total numbers of lines allocated to each operator. At one time this would correctly describe the switchboard arrangements, when it was customary to allot 50 or 60 subscribers to each, a system manifestly far from ideal, as one operator might deal with 150 calls per hour, and an adjacent one 20 or so calls in the same period. These problems have now been properly tackled, and to-day the method is to apportion equally the amount of work, relying upon mutual assistance or team-work to provide for unequal capabilities of the operators, and to prevent an accumulation of calls at individual operator's positions. The work is apportioned on the basis of calls, not lines. To obtain this result records of calls are taken periodically, and the lines on the switchboard distributed as required. The numbers of calling subscribers do not necessarily follow in numerical order. The subscriber when calling lights a lamp, and the operator simply inserts a plug in the adjacent jack and extinguishes the light. The operation, therefore, requires no mental effort.

For some reason telephone engineering has not always been given its proper status and classified as an important branch of the electrical industry, and, curiously, when the development has now reached a stage approaching perfection, the most important branch of the telephone service is not electrical in character, and the engineer who has persistently devoted his life to what may be termed the higher side of the art, finds it necessary also to acquire considerable commercial knowledge. Originally, the problems connected with the running of open wires, aerial or underground cables, from the subscribers to a crowded centre, and the building of switchboards with provision for future extensions gave his activities plenty of scope. Now, when standardisation has taken a firm hold, and the experimental stage has been narrowed down, the traffic side provides a vast field for intelligent investigation, and the function of the telephone engineer which, a short time ago, was to instal lines and build switchboards, is now associated with business and commercial questions controlling the position and size of the exchange, the possible growth, the lay out of the outside

plant and size of the switchboard, distribution of the work, the rate of calling, the character and destination of the calls, and other similar matters which involve the expenditure of huge sums of money.

The introduction of 24 volts pressure on telephone lines brought prominently to the front the question of insulation and taking 1,000 lines under old conditions, on a wet day 40 per cent. tested under 100,000 ohms; the use of Sinclair-Aitken leading-in insulators which introduces a dry section between the leading-in cable and the outside wire raised the insulation considerably, and under the same atmospheric conditions, only 23 per cent. proved to be under 200,000 ohms. An investigation of low insulation and the cause subdivided the responsibility, as follows:—

Outside lines including the leading-in wire ...	37 per cent.
Window terminals	37 "
Office wiring...	19 "
Instruments	7 "

After receiving individual attention, no line tested under 7 megohms. It does not necessarily follow that speech transmission was inferior under the old conditions, although with the transference from open to underground wires insulation difficulties almost disappear.

Touching on the change from overhead wires to cable, Manchester possessed one of the first paper cable systems, and it is interesting to note the increase in the number of wires per cable. In the first installation there were 153 pairs of wires in a 2½-in. cable, and now cables containing 800 pairs of wires in the same diameter are used, as the following will show:—

Pairs.	Diameter of Cable.	Conductor.
	Inches.	Lbs. per Mile.
153	2,410	20
600	2,345	10
800	2,550	6½

The importance of the cable study is exemplified in these figures, and the determination of the standard of transmission is practically of recent date. Using the words of an eminent telephone engineer, the telephone engineer is now able to measure telephone currents with the same ease as the lighting engineer employs the voltmeter and ammeter. The question of handling and providing for a large number of wires has always been present. Was it advisable to bring all the lines into one exchange or split them up into several and connect with junctions? In the first instance, the operator's reach and the space

requisite were practically the controlling features, and the time lost in transferring a call was also a contingent question. Reduction in the dimension of various switchboard apparatus and the introduction of automatic signals and common battery working brought the standardisation of plant within reach, and the latter system places all complication at the exchange, where a skilled staff is available, leaving a minimum amount of work for the subscriber to accomplish with simplified equipment. The less the subscriber has to do, the better for the service, for he is strikingly incompetent as an operator.

Among the innumerable modifications of the original apparatus connected with the public service, the subscriber's instrument has also made a real progress, and the general excellence of the design and workmanship makes it difficult to suggest further improvements, although trouble, of course, does occasionally occur. The same progress is not so generally noticeable in the domestic or private telephone; the retention of the obsolete types of instrument is unfortunate, and whether this is due to inexperience or the borrowing ideas, the same errors are perpetuated, and the consequent difficulty of maintenance brings the industry into disrepute.

The practice of designing or specifying instruments equipped with 4-magnet generators and 1,000-ohm bell coils for internal use, where the maximum line resistance does not exceed 3 or 4 ohms is absurd. In fact, for ringing currents, exactly the same rule applies as with direct currents from batteries, viz., the resistance or impedance of the piece of apparatus operated should be something about the resistance or impedance of the operating apparatus plus the lines, but in the case of lines of negligible resistance one might, very well, use even a 50-ohm generator and corresponding bell. In some switchboards on the market the indicators are placed in series with the line, and series indicators, unless of very low impedance and used on short lines, are, of course, worse from a transmission standpoint than the bridging apparatus; and another point is that with series apparatus, by keeping down the impedance of the indicators, the sensitiveness is generally decreased, so that trouble is experienced owing to the fact that a more powerful source of signalling supply, whether battery or generator, is required. For some reason, also, most trembling bells are wound to 5 ohms resistance, and trouble is experienced when it is necessary to work the bells in conjunction with a cable line of, say, 2 or 3 miles with a resistance of, say, 250 ohms. This should obviously be wound so as to have the same resistance as the average type of line, and there appears to be no reason why the rule of thumb work should apply to the design of local service apparatus any more than it should to the design of long-distance apparatus.

When attention is once aroused, no doubt the ingenuity and enterprise of the manufacturers will speedily find methods to increase the efficiency of this class of telephone. It should be remembered that manufacturers do not, as a rule, instal and maintain installations, which probably explains the foregoing shortcomings, so the following analysis

of faults, taken over a long period and a large number of instruments, given in relative order of importance, may be of interest:—

1. *Wiring.*—Much trouble can be traced to the practice of leaving at each terminal a spare length of wire in the form of a helix which is easily broken. The wire should be stapled direct to the terminals. Faulty design and the placing of cotton-covered wire in unsuitable positions or in steel conduit where moisture and condensation in time break down the insulation.
2. *Primary Batteries.*—The life of a battery varies according to circumstances, but they are often needlessly changed. The correct way to test is to leave the receiver off the hook for at least 5 minutes before making the necessary observations.
3. *Bell Troubles.*—After being adjusted correctly, the chief trouble is caused by cleaning gongs. Intermittent faults in the coils often due to acids used in the manufacture of the bobbin fibre end, it is a difficult fault to localise even with a weak current. A generator circuit will oftentimes overcome the interruption to the circuit.
4. *Instrument Cords.*—The cord represents the weakest part of any system and is known as the telephone man's scourge. It is, therefore, wise to reduce the cords to a minimum, for this reason the hand combination instrument is really the most inefficient and consequently the most expensive instrument to maintain. Its popularity is due to the convenience offered.
5. *Transmitters.*—Damage by pencils and the packing of granulated carbon. These troubles are largely overcome by the use of the solid back microphone chamber with perforated mouthpiece.
6. *Generators.*—Cut-out troubles. Short-circuiting the generator due to breakdown of insulating pin, oil and metallic dust is generally responsible, especially in certain types of instruments where the frame is used as a common connection.
7. *Receiver.*—Represents the first telephonic apparatus invented, and left the hands of the inventor in an almost perfect condition; it offers very little scope for improvement. The change from bar to horseshoe magnets is perhaps the most important. A diaphragm too close to the magnet is a trouble which can be ascertained by the sound emitted when flicked with the finger, the sound should be hollow. Freedom from dirt is essential.
8. *Lightning Arrester.*—Generally of the serrated type open and exposed to dust and foreign matter, which causes short circuits. Terminals left exposed to the atmosphere will, in a short time, cause trouble.
9. Fixing instrument to damp walls introduces various troubles.
10. *Cradle Switch.*—Such causes as poor springs and contacts, and the accumulation of dirt interfere with the regular working of some types of instrument switch-hooks.

A glance at the common battery standard instrument will show the great improvements and modifications in favour of low maintenance costs, and there is apparently no reason why these features should not be introduced in other types. For small installations it is not always advisable to instal a common battery equipment, but the time has now arrived when the advantages of a common battery system should be universally appreciated; but unless manufacturers take in hand the necessary educational work opportunities will, for the time being, be lost and obsolete systems installed.

The advantages a common battery system offers may be subdivided under the headings of Line, Instrument, and Switchboard :—

(*a*) The common battery instrument dispenses with the local battery and generator. The simplified instrument consisting of bell, receiver, induction coil and transmitter, with the addition of a condenser, supplies all requirements, and the act of taking off and replacing the receiver gives a definite call and clear by making and breaking the circuit for direct current from the exchange battery.

(*b*) *Line.*—The line is practically under permanent test, and faults are automatically recorded.

(*c*) *Switchboard.*

1. Responsibility is concentrated to quite 80 per cent. efficiency.
2. Automatic calling is provided.
3. Automatic supervisory signals are provided for both the calling and called subscriber, showing the operator the state of the connections.
4. Uniformity of speech is provided by eliminating the local battery's variation in voltage.
5. Saving in space on the switchboard is of great importance.

In a common battery system accumulators are usually employed, but there is no reason why suitable primary cells of low resistance should not be used for small plants.

The subject is too wide to be dealt with completely in one short paper, for the problems past and present are both numerous and weighty, and the future presents a remarkable field for activity.

Generally speaking, the telephone has yet to be properly developed in connection with floor-to-floor messages, and there is still preference for needlessly wearing out the staircase, calling heads of departments away from their work, banging of doors, and general disturbances; all these objections can be eliminated and an immense saving effected by making it a rule to telephone. The stairway can be left free for customers, messengers dispensed with, a great saving effected, and quickness and discipline assured. The cost of installing a private telephone apparatus may amount to anything from £1 to £8 per station, depending upon the type of installation and the quality of the

apparatus, but the cost of maintenance should amount to a small item, provided the apparatus is carefully selected and installed.

The system to be adopted should be carefully considered, and where a reasonable number of lines are available the switchboard system is undoubtedly the best. The cost of an operator is certainly an item, but it must be remembered that the telephone and the operator save the time of important and highly paid officials and increase business. Extensions can be added from time to time with no difficulty and little expense; also, should one instrument be out of order, the trouble is restricted to that line and the remainder work as usual.

The intercommunication system differs chiefly from that already explained in that it throws the operating on the caller and is necessarily limited in scope. The expense of bringing the total number of wires to each instrument is considerable, and the general practice of adopting a single-line system to reduce expense produces overhearing and cross-talk, which depreciates the value of the system generally, and if manufacturers desire to retain this principle they might, with advantage, devise some method of at least minimising the trouble. Assuming that the induction coil transforms up to twenty times, 3 volts alternating potential difference on the primary would mean 60 volts on the secondary and on the lines, and as cross-talk is directly proportional to the line potential, it is possible that some reduction in the impressed potential on the line might be advantageous.

It is not unusual for the average number of calls per station to exceed 10 calls per day, and if we consider a typical equipment where 50 instruments are installed this means 500 calls and conversations daily. Reckoning the value of the conversations at the very low rate of ½d. each, it follows that the actual value of the traffic in the installation amounts to no less than £312 10s. per annum, the actual cost of the installation being slightly over £200, and the cost of maintenance about £15 annually.

When we consider, in addition, the great saving in time and improved discipline, it is easy to see how the telephone call may be made a most valuable money saver, but the equipment must be suitable for its work, efficiently installed and efficiently maintained.

Discussion.

Mr. Aitken.

Mr. W. Aitken: The ultimate end aimed at in telephone engineering is speed; moreover, telephone operating is becoming more and more automatic. The author has shown in his slides operating that is strictly manual. On the busy junction positions, however, and sometimes on even the local positions, the operator is relieved of part of this work. The ringing, for instance, is automatic; in many exchanges the insertion of the calling plug rings the subscriber intermittently until he answers. Perhaps power and light engineers do not quite realise to what an extent the telephone engineer encroaches on their domains. In the power plant for an exchange they may deal with a

Mr. Aitken.

generator giving 1,000 amperes, accumulators having a capacity of 6,000 to 7,000 ampere-hours, and the power board is perhaps as complicated as that of many power stations. An exchange must be carefully protected against excessive current in any direction by fuses, and the subdivision is now very fine, *e.g.*, a fuse is now provided for each cord circuit. On a 10,000-line exchange there will be practically one million spring-jacks, which have to be wired up in such a way that there are never any faults. The work has to be done in a very perfect way, because faults are so difficult to get at. The author also dealt with the insulation of lines in common battery systems, and showed how the insulation of the lines had been raised by the use of the Sinclair-Aitken insulator. Special insulators in some cases now equal in number the line insulators used. This is accounted for by the great amount of underground cable used, and by the underground distribution leading direct into the buildings in many cases. The author rather blamed the manufacturers for the design of the apparatus; he said we designed 1,000-ohm bell coils and generators with 500 ohms resistance to put in connection with an internal installation with a line resistance of a few ohms. The manufacturers would design apparatus that would be suitable for internal installations, but consulting engineers frequently specify what is to be supplied. With regard to the troubles of the telephone service, the author blamed the subscriber very badly. Some people go so far as to say he must not be allowed to do anything at all, but must take the telephone off to "call," and put it back to "clear." Coming to the standardising of telephone apparatus, I do not much believe in standardising telephone apparatus. It is a progressive science, and whilst we have reached almost perfection in the manually operated multiple switchboard, it is beginning to be found that it is too cumbersome, and gradually there is a leaning towards automatic systems. If the automatic system should come, then the subscriber will be asked to do something more. Instead of merely taking the telephone from the switch-hook, he will be asked to move a finger-plate to spell out the figures of the line he desires to call, when he will be automatically and instantaneously connected therewith. That system seems to me to have very fine features. There would be no concentrating in one building 30,000 lines, with the possibility of a fire cutting off that number. With an automatic system you would be able (as the system is a "trunking" or cross-connecting system) to divide the subscribers' lines into smaller units, and an accident to one unit would then only affect a comparatively small number. I quite agree that cords are the bugbear of the telephone engineer, and think it a point in favour of an automatic system that no flexible conductors are used. The author also mentioned transmitters, receivers, and arresters. With regard to arresters, serrated arresters should never be used. The carbon arrester and its virtues are well known, and should be adopted. One of the most interesting features of common battery equipments is the small exchange. It was the practice for some little time to draw current over the direct line,

Mr. Aitken. and feed extensions from the same circuit by introducing capacity and self-induction and choking down the speech-waves. Now that has been abandoned because of the liability of the exchange line having an accident and cutting down the whole service; and current is now supplied over feeder wires. Of course, with small private installations, where no connection is required with the public service, there is no reason why a primary battery should not be used. The author's figure for the maintenance of an exchange—viz., £15 only—seems to show that he does not believe in paying much for his operator. The inter-communication system is most convenient, but its use ought to be restricted. I should be pleased to hear the author's opinion as to what is the maximum number of lines that ought to be used in an inter-communication system.

Mr. Guy. Mr. A. F. GUY: In the new post offices that are being erected now the general tendency is to build a telephone trunk exchange considerably larger than the telegraph instrument-room. In one office not many miles away the former is almost double the size of the latter; that fact of itself will show how great an increase has taken place recently in telephone business. The author refers to troubles in generators; he speaks about short circuits, etc., occurring in magneto generators which have one pole connected to the framework. I suppose he is referring to small generators of the multiple permanent magnet type of perhaps $\frac{1}{10}$ H.P., but with larger generators, say $\frac{1}{2}$ H.P., I find no trouble of any kind. The motor-generator used for the trunk exchange in Manchester has given every satisfaction during the past twelve years.

Mr. Morshead. Mr. L. R. MORSHEAD: There is no doubt that, as the author pointed out, there are a good many annoyances created by the delays and ineffective calls that occur, the reasons for which are seldom known to the subscriber. The delays, the leaky lines, the buzzing and roaring of the wires during the carrying on of an important and urgent business communication, I think, are responsible for many spoiled days and ruffled tempers. Does it not seem possible that some system may be eventually evolved whereby calls could be stored as put in? There is a great deal of time wasted in calling up other subscribers, and getting the reply "engaged." Now, on the underground railways in London, in connection with the electric signalling arrangement, they have a system whereby the signalling of the trains is automatically stored up, and only a single one is shown in the operator's cabin at a time. There is, of course, no comparison between the telephone system and railway signalling, but it seems that something of this nature might eventually be possible. In connection with trunk calls, these are frequently entirely ineffective owing to some disturbance on the lines, perhaps not altogether under the control of the telephone authorities. In one case I had four trunk calls through to London to try and get hold of one man. I got through each time, but owing to the noise it was quite impossible to carry on any conversation. The money paid was wasted, and there is no redress.

Mr. Plummer.

Mr. T. PLUMMER: I am sorry the author has not dealt further of the engineering side of the question; as far as the paper goes, practically everybody must agree with him. He has given us some figures in connection with the National Telephone Company's calls, and these calls work out according to the number of lines at Manchester at about 10 calls per line per day, and London about 8. These are somewhat higher than the usual number of calls per line, and I should like to know if the author could give us some idea whether this is due to the prevalence of the inclusive rate as against measured rate. I also quite agree with the point he makes that subscribers are not aware of the full advantages at their disposal. Dealing with the question of the busy rush at certain hours of the morning, between 10 and 12, I might also remark that this is also the "peak" of the load in connection with trunk calls. At the Manchester trunk exchange, which Mr. Guy says is the largest in the kingdom, the trunk calls between 10 and 11 a.m. daily amount to 10,000. Of these 4,000 originate in Manchester, and 6,000 are for Manchester originating at outside places. Between 11 and 12 this falls off to 8,000, of which the outgoing calls are 3,000 and the incoming 5,000. Coming to the great improvement in the manufacture of paper core cables, this is partly brought about by the agreement made in 1905 between the Post Office and the National Telephone Company. Under this agreement certain standards are laid down—for example, that the combined efficiency of the subscribers' line and junction shall not exceed so many miles of standard cable, having a conductor resistance of 88 ohms per mile of loop and wire-to-wire capacity of 0·54 microfarad per mile, with insulation not less than 200 megohms between each wire of a pair. This has enabled the company to reduce the weight of conductor in subscribers' cables within a short distance of the exchange to 6½ lbs. per mile, which represents the minimum size from a mechanical point of view, apart altogether from its electrical efficiency. The author does not give us any information as to whether it is advisable to bring all lines into one exchange or bring them into several. In the new "City" exchange recently opened by the Post Office in London there is no multiple on the subscribers' board at all. It was found that the number of junction calls in London forms such a very high percentage—I think over 80—that the subscribers' multiple was abandoned altogether on the local board. All calls that come into the City exchange have to be transferred either on outgoing junctions, or for subscribers on the same exchange; they go across the room to an incoming junction-board, and in that way they get on to the subscribers' multiple. Cords are an important matter, and there is a fortune awaiting the man who will bring out a decent telephone cord. There are cordless switchboards on the market, but they do not appear to have come into public favour. As to the defects of the hand micro-telephone, Mr. Wilson simply refers to the cords as being the trouble. There is another feature which also makes for inefficiency, and that is the varying distance between the ear-piece and the mouth-

Mr. Plummer.

piece. There is no reference in the paper to the very important question of increasing the efficiency of telephone cables by loading by means of inductance coils, as suggested by Pupin. It may be of interest to mention that the Liverpool-Manchester 100-lb. conductor air-space telephone cable has been under experimental treatment by the Post Office for some six years past. The cable is 38·5 miles in length, and the first sets of coils, inserted at mile intervals, although increasing the efficiency of the cable, gave rise to trouble through loss of insulation at the leading-in points. About two years ago, however, further experiments were made, and improved types of coils were fitted, one with an inductance of 100 millihenrys and the other 133 millihenrys, at 3-mile intervals. The unloaded cable has an efficiency represented by 17 miles of standard cable, whilst the loading at 3-mile intervals has reduced it to about 9 miles with terminal losses, or about 5 miles when the cable wires are extended so as to overcome these losses. The results have been so satisfactory that the new 208-wire telephone cable just laid between Liverpool and Manchester contains conductors of 70 lbs. per mile only, and these will be loaded at intervals of about 2½ miles.

Mr. Latimer.

Mr. F. D. LATIMER: On page 412 we find a tabulated statement respecting various types of dry-core cable with their respective sizes; the information given in connection with the 800-pair is, however, not in accordance with National Telephone Company's practice. The diameter of 2·55 in. for cable having 800 pairs would be quite correct for 10-lb. conductors—not 6½ lbs. as quoted; an 800-pair cable with 6½ lbs. copper constructed to comply with the National Telephone Company's specification would have a diameter of approximately 2·3 in.; on the other hand, if the diameter and conductor columns are left as stated, the number of pairs should be about 1,100. The greatest number of pairs with 6½ lbs. copper which it is reasonable to expect could be enclosed in a lead sheathing of 2⅝ in. external diameter, and with a maximum mutual capacity not exceeding 0·08 microfarad, per mile would seem to be about 1,200.

Mr. Whalley.

Mr. A. WHALLEY: It is interesting to refer to the great development that has taken place in the industry from the manufacturers' point of view. Up to five or six years ago, practically the whole of the equipment of the common battery exchanges shown on the screen to-night was made abroad, but there are two or three firms in this country, including the owners of foreign patents, who have laid down plant, and everything is now made in this country. The Post Office is to be credited with a large share of this encouragement of British industry. It appears for the moment, however, as though the manufacturing capacity had overtaken the demand. As regards the development of the telephone industry—the keynote of the paper—manufacturers are more than ready to meet an increased demand. Another development is due to the agreement between the National Telephone Company and the Post Office. A bargain for one to sell to the other could not be concluded without agreeing on standards of

efficiency and quality of instruments, plant, cables, and lines. The standards adopted have set a high mark of quality and efficiency, and every important manufacturer in this country can now supply to these standards. While in America they have an output of telephonic apparatus many times greater than ours, no universally accepted standards have so far been adopted. The use of telephones for communications inside business premises, etc., is another large subject dealt with in the paper. The telephone exchange standard of quality will be applied to the special instruments and apparatus, when the importance of reliability and low maintenance costs is realised. The author gives a figure for the cost of installing fifty telephones. The cost per instrument is low, and allowing for depreciation and maintenance, the annual cost should be below £2 per instrument per annum. Mr. Whalley.

Mr. S. J. WATSON: The point made by the author on page 410 to the effect that the subscriber is only alive to the delay which he personally experiences, and is not interested in the irregularity occasioned by his own methods, is very true, and if users would pay greater attention to the loss of time which must occur through this cause, all subscribers would benefit by the improved service. Mr. Morshead raised a question which is of importance, and that is, Why cannot messages be stored, and passed through as soon as convenient? It is the old question of improving the load factor, and if an automatic apparatus can be devised which will enable those beautiful curves to be flattened out, telephone rates will be largely reduced. I am sorry that no details have been given concerning automatic telephones, and I understand considerable improvement in this direction has been made recently, and any information would have been of interest. To make public telephones a greater success it is necessary to extend the usage. Later on, when the National Telephone Company's business is taken over by the General Post Office, it will be a simple matter for the Government then in office to ensure success by passing a short Act of Parliament making it compulsory for each householder to have, and to pay for, a telephone connection. Mr. Watson.

Mr. A. R. BENNETT (*communicated*): The advantages of the all-night service are so important that it is difficult to understand the reluctance to begin it which was exhibited in so many quarters. As late as 1895 new switchboards for many thousand subscribers were fitted in Berlin and other German cities without any provision being made for night service, and other Continental countries were just as backward. The importance is by no means to be measured by the number of calls passing during the night but by their urgency, which is sometimes extremely great. Without doubt many lives and much property have been saved by the existence of night telephones. A notable example took place in 1885, soon after the exchanges already mentioned were opened on the Cumberland coast. The barque *Cygnus* went ashore one stormy night near Workington, and the crew were in the utmost peril for a good many hours. The Post Offices at Mr. Bennett.

Mr. Bennett. Whitehaven, Workington, and Maryport had, of course, been closed at 8 or 9 o'clock the previous evening, and nobody in connection with them could be roused or found, so that for all practical purposes the Cumberland coast was devoid of telegraphs. The coastguard were, however, able to concert measures for rescue through the telephone exchanges, first by means of the lifeboats belonging to the three ports, and when they had failed, by the rocket apparatus, which was eventually successful. On this occasion the telephone system was used as a telegraph, as none of the Board of Trade or lifeboat officials had telephones in their houses, and the numerous messages had to be written down and delivered by girl operators, who were roused from their beds, and very willingly trotted about the three towns in the small hours and in heavy wind and rain. The Board of Trade thanked the Company for doing what its sister Government Department had failed to do. Yet I notice that, judging from questions recently asked in Parliament, the Post Office remained so unconvinced to this day of the utility of the night service that they are proposing to discontinue it at some of the exchanges where it is already in force.

Mr. Wilson. Mr. L. E. Wilson (*in reply*): As regards Mr. Aitken's question respecting the maximum number of lines that could successfully be used in an intercommunication system, it may be answered that the intercommunication telephone of above ten lines is not a complete success. The finality of the common battery system is a very wide question. Whilst admitting the perfection of the system as a manual device, there are grave objections to it; the apparatus-room occupies a considerable amount of space, and is very costly. The automatic switchboard has advantages, and will develop in time, doubtless as a large feeder to large exchanges. Mr. Guy's remarks are very interesting, and, as he surmises, the troubles connected with generators do not refer to a special machine under skilled control at the exchange, but to the large number of generators situated at the subscribers. Mr. Morshead's experience of delays to London were no doubt caused through an insufficient number of trunks. Dual control is wrong, and does not assist in these operations, and it is a matter of regret that the same progress is not so noticeable as with the local service. The suggestion to store up calls as in railway signalling would not be practicable, as the same principle applied to telephone calls would engage the line and debar any one else establishing connection whilst waiting. Bringing an unlimited number of wires into one exchange is a questionable practice. The limit to the human reach is 10,000 subscribers, and the same applies to fire risks also. The stoppage of 15,000 telephone lines and practically all the trunk wires would be a commercial disaster. Standardisation of the common battery switchboard is an accomplished fact, but there are still weighty and numerous problems in connection with the lay-out of a complete telephone equipment, the transmission of speech and traffic questions generally.

RECENT DEVELOPMENTS IN THE TRANSMISSION OF ELECTRICAL ENERGY AT HIGH TENSIONS ON OVERHEAD LINES.

By Professor E. W. MARCHANT, D.Sc., Member, and E. A. WATSON, M.Sc., Student.

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INTRODUCTION.

The transmission of electrical energy over long distances is a problem which, not unnaturally, has received far greater attention in America than on the Continent of Europe. The plentiful supply of cheap coal in England has rendered the consideration of long-distance transmission schemes almost unnecessary, since, in most cases, it is as cheap to carry coal as it is to transmit electrical energy. In a country, however, where coal is not plentiful, but where water-power is abundant, and where it is possible to obtain wayleaves at a reasonable rate, transmission of electrical energy becomes economically possible over very long distances.

The two great developments which have taken place within the past few years are located respectively at the Niagara Falls and on the Pacific slope of Western America. At Niagara there is a very large supply of water, estimated to produce a total horse-power of from 7 to 10 millions, and, at the present time, there are five power stations for the supply of electrical energy, giving a maximum output of 320,000 H.P. These supply power over a distance of 150 miles. Very shortly this distance will be extended to 250 miles, and a system of distribution will be in operation which, if it were installed in England, would supply the whole country with the electrical energy it required from one central station.

The effect of this vast source of power on the industrial development of the district in which it is placed has been enormous. The great manufacturing city of Rochester receives all its energy from Niagara, while the tramways of Syracuse, Geneva, West Seneca, the interurban lines Syracuse, Lake Shore and Northern, Syracuse and South Bay, Rochester and Geneva, Rochester and Mount Morris, Buffalo, Lockport and Rochester, Buffalo and Hamburg, and Buffalo and Dunkirk, all obtain their supply of power from the same source. In Canada, Toronto is now using Niagara power for its tramways and lighting,

and a project is in course of completion for extending the transmission to Hamilton and London. At the present time it is estimated that a population of 40 million people reside within the area which represents the field of distribution for Niagara Falls, and in future years, as the electrification of the railways progress, it is certain that the Niagara district will become an unrivalled centre for manufacturing industries. The transmission of power from Niagara represents an almost unique case, since in no other single place in the world (except possibly at the Victoria Falls of the Zambesi) is there located so vast a supply of power (see Fig. 1).

On the Pacific Coast the problem has been of an entirely different character. Large towns have sprung into existence chiefly as the result of mining and agricultural enterprise, and as fuel is expensive the supply of electrical energy for lighting and tramways from water-power has led to the development of many comparatively small powers, the energy from which is distributed, sometimes, for as great a distance as 250 miles. The chief centres of power supply on the Pacific Coast are the Puget Sound District, containing Vancouver, Seattle, Tacoma, and the other cities in the vicinity, and that in the neighbourhood of San Francisco. A similar state of affairs exists in Colorado, where, for example, a water-power of only 10,000 k.w. has been developed for the supply of electrical energy to the city of Denver, 160 miles distant.

One of the most interesting of these systems is that for the supply of electric power to the city of San Francisco, which is under the management of the Pacific Gas and Electric Company (see Fig. 2). No less than eleven water-powers are connected to this system, some of only 100-k.w. capacity, the power for which is obtained from water used for irrigation purposes; these are coupled in parallel on a single network, covering in all an area of 30,000 square miles, extending nearly 250 miles along the Pacific Coast, and supplying power and electric light to the towns and villages within its district. The total length of 60,000-volt overhead line on this network is over 1,000 miles. Such a system as this would only seem to be economically possible in a district where fuel was exceptionally dear, and it is interesting to note, therefore, that although coal is far from plentiful, there is a large supply of fuel obtained from oil wells in the neighbourhood of Bakerfield and Los Angeles.

The development of the water-power has not been due entirely to the cost of fuel. A great factor in making these systems a commercial success is undoubtedly the low price of land and the cheap rate at which wayleaves can be obtained; the cost of land for certain transmission schemes was stated not to exceed £60 per mile of line.

Many water powers, involving large capital expenditure in the conveying of water to the reservoirs, have been developed. The longest distance over which water is carried is at the Electra station, where the distance from the source of supply to the reservoir is 30 miles. There are, however, many other cases in which

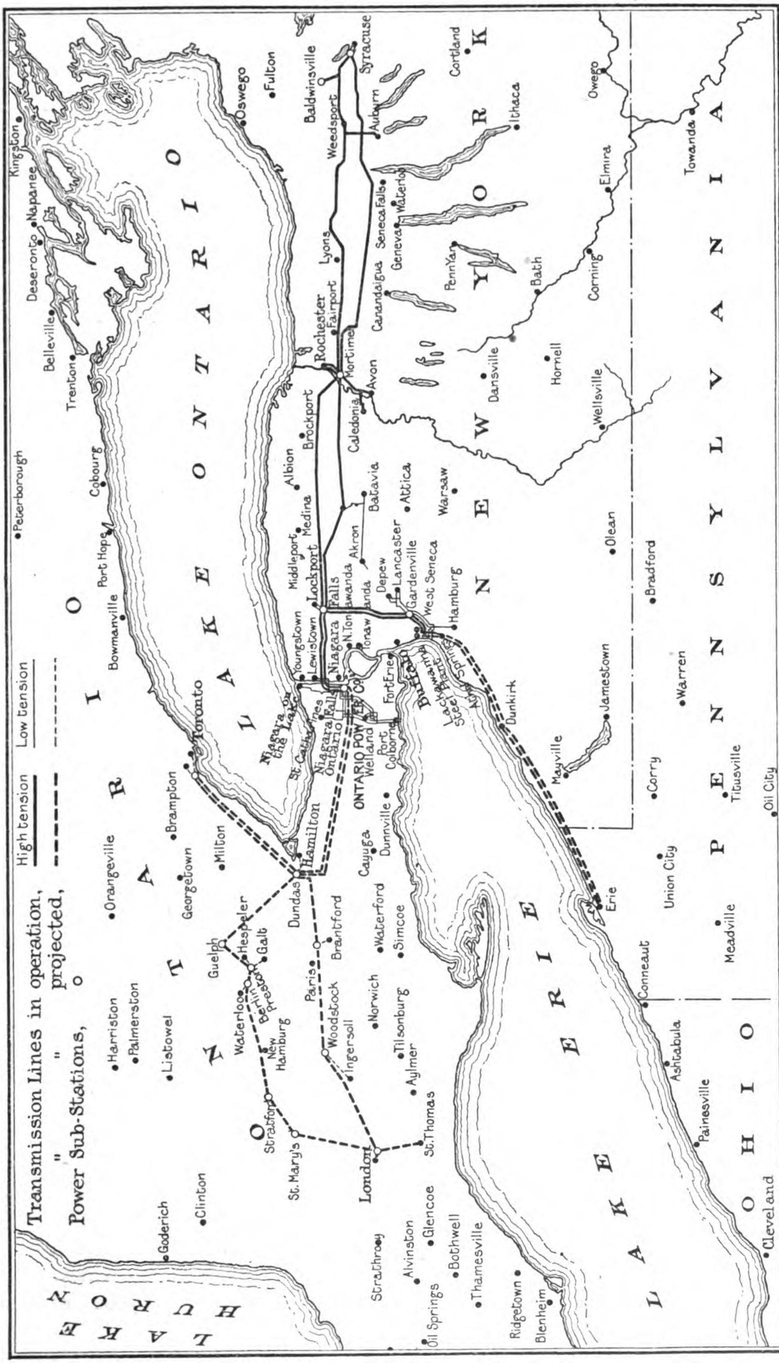

FIG. 1.—Map showing Transmission Lines near Niagara.

water is carried several miles before it can be used for power purposes. At Electron the station which supplies Tacoma and Seattle, the water is carried in a wooden flume along the side of the Puyallup Canyon for 10½ miles to the reservoir. At Island Bar the new station of the Great Western Electric Power Company, water has to be brought through a concrete-lined tunnel 2½ miles long, while at the Centerville station of the Pacific Gas and Electric Company the water

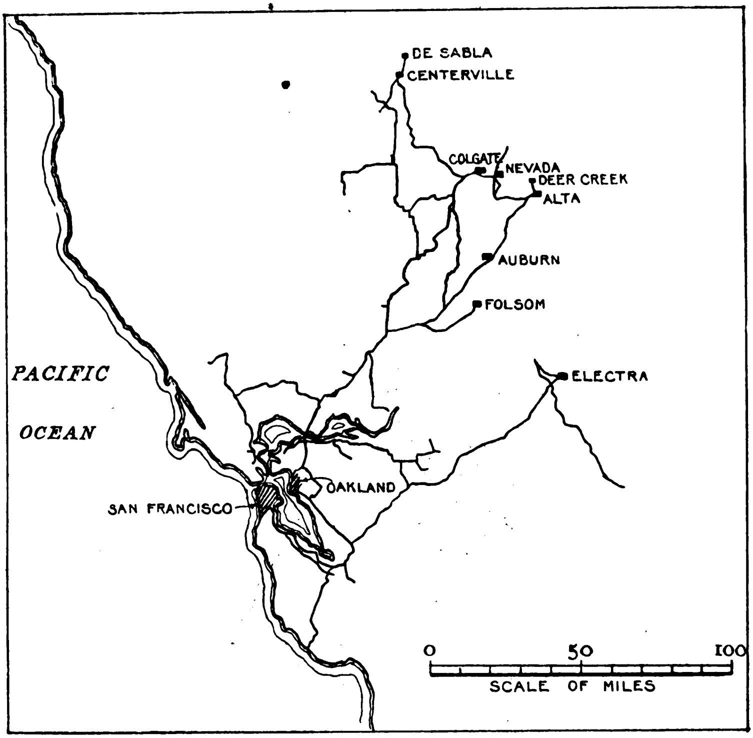

FIG. 2.—Sketch Map of System—Pacific Gas and Electric Company.

is conveyed in an open ditch for a distance of 9 miles from the tail-race of the station at De Sabla.

A study of these stations makes it evident that many water-powers in this country which have hardly been considered as of practical utility may ultimately be developed, to the great benefit of the surrounding district, provided that the necessary wayleaves for the transmission lines can be obtained at a reasonable rate. In this connection too great emphasis can hardly be laid on the advantage which a new country possesses in having land which can be used for purposes of

this kind without payment of heavy dues, though it may be hoped that even in this country, when the great economic and industrial advantages of a cheap supply of electrical energy are thoroughly understood, it may be possible to use transmission lines over distances much greater than have hitherto been attempted. The standing charges involved in the payment of wayleaves is a very heavy tax on a station, particularly in a small station such as most hydroelectric stations must necessarily be in England.

In order that economical transmission of electric power may be made over long distances it is, of course, necessary that a high voltage should be employed. The standard pressure at present in use is 60,000 volts 3 phase. This pressure is used in nearly all transmissions of 50 miles and over, and appears to give rise to no practical difficulties in operation. The first station to use this pressure was put in operation almost five years ago, and among the earliest are the station of Electron, on the Puget Sound, and that at the De Sabla River in California. The transmission lines for this pressure are entirely overhead, and are run with a clearance of 6 ft., the insulators being usually supported on wooden poles. In several cases stations have been designed for pressures up to 110,000 volts; in many of these, lower pressures are being used until the load on the station is sufficiently large to necessitate the higher pressure being employed. The station at Island Bar commenced operation at 110,000 volts on October 1, 1909, along its transmission line of 153 miles, while that of the Central Colorado Power at Shoshone has been in operation at a pressure of 90,000 volts since May, 1909. The efficiency of transmission over these distances is usually figured at 90 per cent., and it can, of course, be maintained nearly constant as the load on the station increases by raising the working pressure.

Higher voltages are undoubtedly possible at the altitudes of Colorado and the Nevadas than could be used on similar installations in our manufacturing districts; but, allowing for all effects of climate and atmosphere, there is no doubt that there is no great technical difficulty involved in the use of much higher voltages than have hitherto been attempted in this country.

Technical Considerations.

(*a*) *The Limit of Transmission Voltage.*—In the early plants the voltage which could be employed on the line was limited by the insulation of the transformers which fed it. Improvements in transformer design and insulating material and the adoption of oil immersion soon raised this, until the limit was the line insulator, which was then of the ordinary pin type.

With the advent, during the last few years, of the so-called suspension-type insulator any number of which may be placed in series, this limit has been removed so that, at the present time, the possible voltage is only limited by the production of a corona or brush discharge from the line itself.

This corona is due to the electric stress produced in the neighbourhood of the wire by the electrostatic charge which it carries being greater than the air can stand. Disruption of the zone of air next the wire takes place accompanied by light, sound, and chemical effects, and a serious loss of energy. A corona on a high-tension line must never be allowed, as the power loss which accompanies it will amount to a very considerable figure.

The stress which will be produced in the air at the surface of a transmission line depends on three factors :—

1. The potential difference between lines.
2. The diameter of the wire.
3. The distance apart of the wires.

The following expressions give the electric stress in terms of these factors :—

1. Two parallel wires :—

$$\text{Stress} = \frac{V}{2a \lg_\epsilon \frac{d}{a} \cdot \frac{1}{\sqrt{1 + \left(\frac{d}{2h}\right)^2}}}.$$

2. One wire and earth :—

$$\text{Stress} = \frac{V}{a \lg_\epsilon \frac{2h}{a}}$$

(where V = maximum line voltage ; d = distance apart of wires ; h = height above ground ; a = radius of wire).

3. Three wires at corners of a triangle (ordinary 3-phase arrangement) :—

$$\text{Stress} = \frac{V}{\sqrt{3} \lg_\epsilon \frac{d}{a} \cdot \frac{1}{\sqrt{1 + \left(\frac{d}{2h}\right)^2}}}.$$

These formulæ are only approximate, but hold with quite sufficient accuracy when the distance apart of the wires is large compared to their diameter.

They only apply when the potentials of the system are symmetrical —that is to say, in the case of a 2-wire system when the potentials of the two wires are equally plus and minus and in the case of a 3-wire system, when the lines are fed with a balanced 3-phase supply and the neutral-point is earthed. Any deviation from these conditions will inevitably increase the stress on one of the wires, the stresses given being the least which can possibly exist.

The value of the electric stress which can be allowed in the neighbourhood of a transmission line is not a constant for all conditions, but depends on a good many factors, some of which have not been very definitely investigated. In the first place, it has been demonstrated

beyond any doubt that it depends to some extent upon the size of the conductor, rising as the conductor size decreases according to the curve shown in Fig. 3. This is especially noticeable for small wires, but for wires of the sizes ordinarily used in transmission work the range is only small. Secondly, the electric strength of the air is known to become less as the atmospheric pressure is decreased, so that at high altitudes a corona is more easily formed than at low ones, the relation between electric strength and air pressure being given approximately by the expression:—

$$R = R_0 \left(0{\cdot}2 + 0{\cdot}8 \frac{p}{760}\right)$$

where p is the pressure in millimetres of mercury.

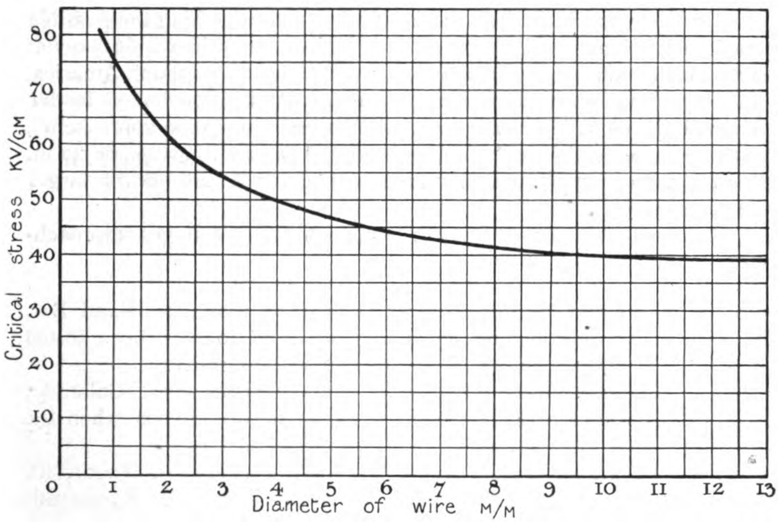

FIG. 3.—Relation between "R" and the Diameter of the Wire.

A similar lessening of the electric strength is also produced by an increase of temperature, the law being linear in this case also.

The condition of the surface of the wire and the presence of water vapour and floating impurities in the atmosphere affect the electric stress allowable in a way which is not yet fully understood.

The voltage of discharge from a perfectly clean wire seems to be little affected by the presence of water vapour in the atmosphere, but if the wire be dirty not only does the discharge in any case occur at a lower voltage, but the voltage is lowered still further if water vapour is present. For this reason there has been considerable discrepancy between the results obtained by various workers on the subject. Laboratory tests made on clean wires have given values of the critical

stress 50 per cent. or more greater than actual tests on transmission lines in manufacturing districts, where the wires would soon become dirty; whereas, tests on lines in remote mountainous districts, such as the Rocky Mountains in Colorado or the Sierra Nevadas in California, have given figures agreeing very closely indeed with laboratory tests.

For the present it is suggested that the figures given in Fig. 3 should be used combined with a factor of safety which should have, approximately, the following values:—

Large towns or industrial districts especially near sea-level, *e.g.*, Lancashire, etc.	1·8–2·0
Ordinary open English country	1·5
Mountainous or other districts far from any source of contamination of the air	1·2

The systems which use a working voltage approaching the possible maximum are as yet but few in number. The ordinary 60,000-volt plant, of which there are numerous examples throughout America, does not approach the limit, except it be on an occasional short feeder of small diameter. The main transmission line of a 60,000-volt scheme, even if of copper, is rarely of less than 000 B. and S. gauge, or ·47 in. diameter, and very often an aluminium conductor of considerably larger size is employed.

The lines which are at present being worked at voltages approaching the limit are as follows:—

1. The Great Western Power Company's plant, at Island Bar, California, 110,000 volts, which is said to have been tested at 150,000 volts without any sign of luminosity.
2. The Central Colorado Power Company, at Shoshone, Colorado, working at 88,000 volts, to be raised to 110,000 when the load requires, and already tested at that figure.
3. The Grand Rapids, Muskegon, plant, working at 100,000 volts. Photos have been published showing a luminosity on this line, but it is doubtful if there is a true corona.

The table on page 431 shows the stresses existing on these lines and the factor of safety which has been allowed.

It will be seen that, allowing for altitude, the plant which is working the nearest to the limiting voltage is that of the Central Colorado Power Company. This line is in a mountainous district, where the air is very clean and the rainfall slight, so that the factor of safety is probably sufficient, even though some parts of the line rise to more than 10,000 ft. above sea-level.

Although theoretically a line at a high altitude should discharge at a lower voltage than one at sea-level, this is often offset by the greater purity of air at high altitudes, and the way in which the surface of the wire retains its original smoothness.

(*b*) With the exception of the few comparatively small plants installed in France and Switzerland, all the modern transmission

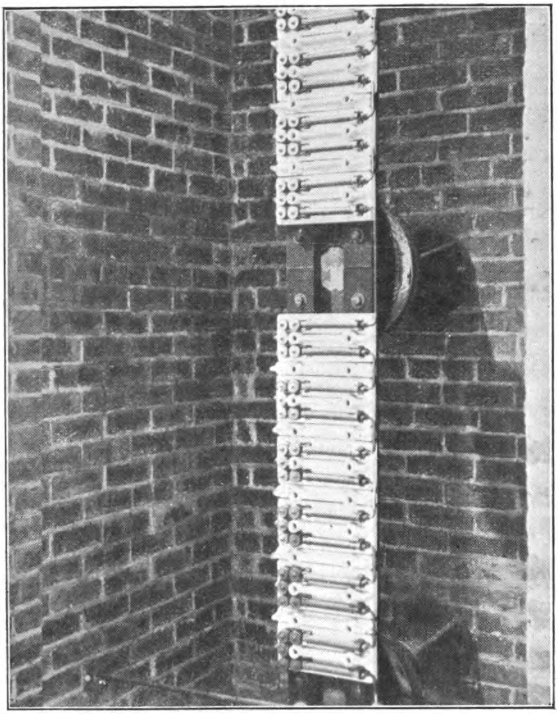

FIG. 4.—Würts Lightning Arresters, Electron.

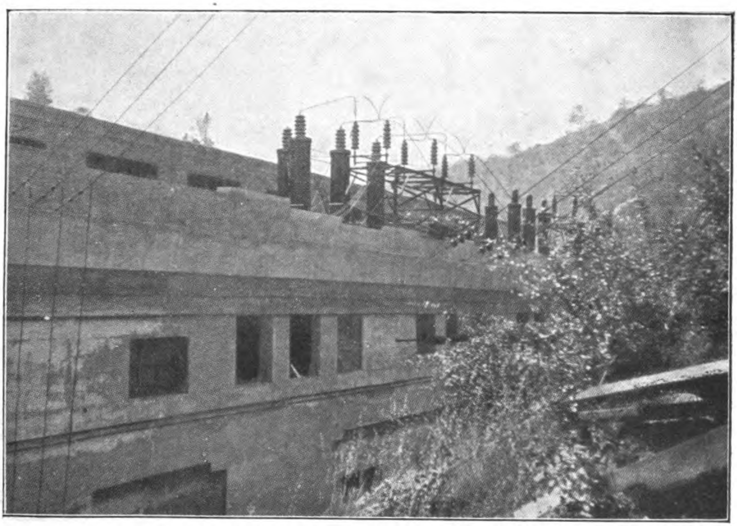

FIG. 5.—Electrolytic Lightning Arresters, Island Bar (Cal.).

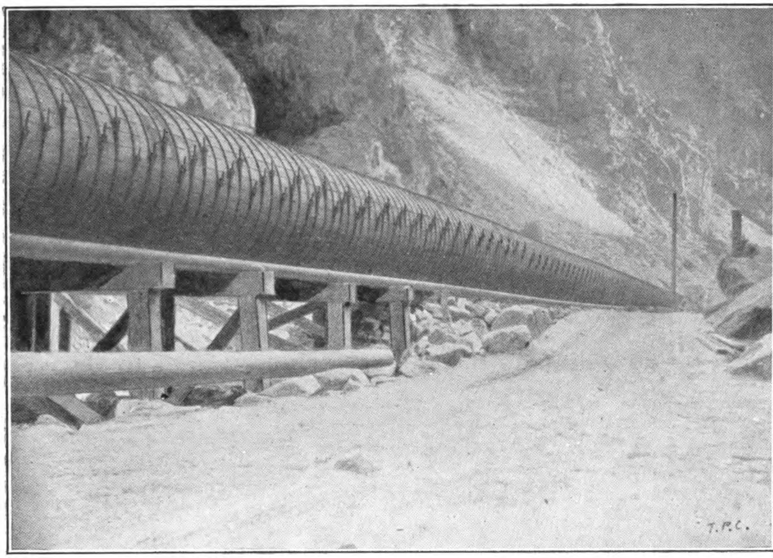

FIG. 6.—Wooden Pipe, Central Colorado Power Company.

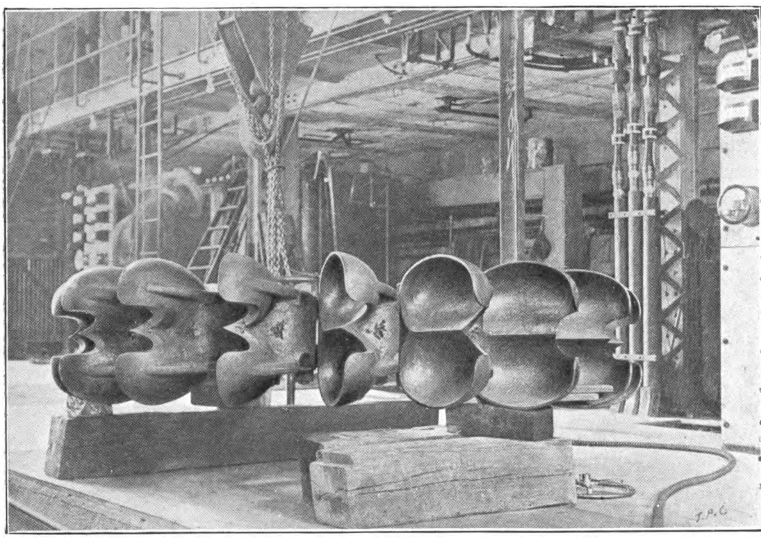

FIG. 7.—Doble Wheel at De Sabla, California.

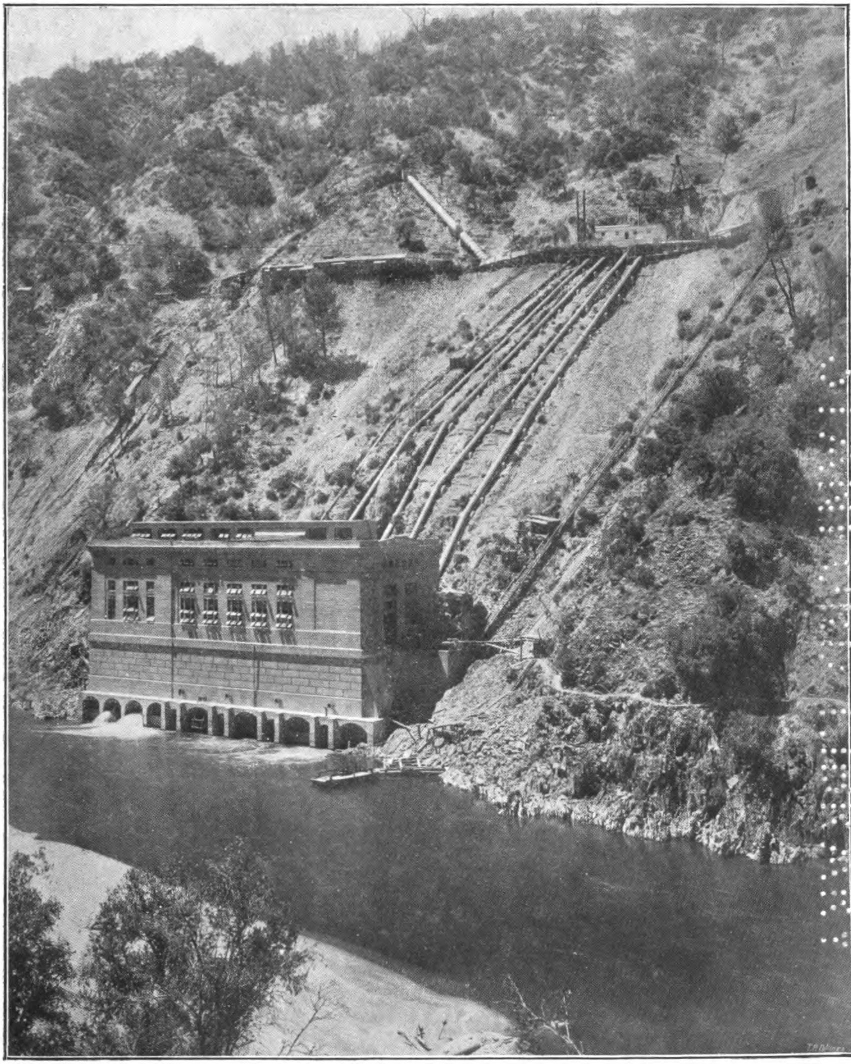

FIG. 8.—View of Power Station at Island Bar, showing Surge Pipe.

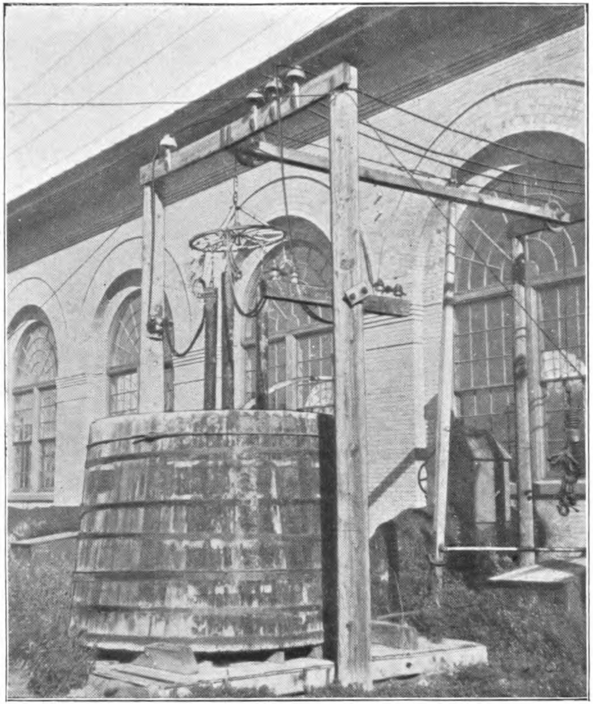

FIG. 9.—Water Load, Ogden.

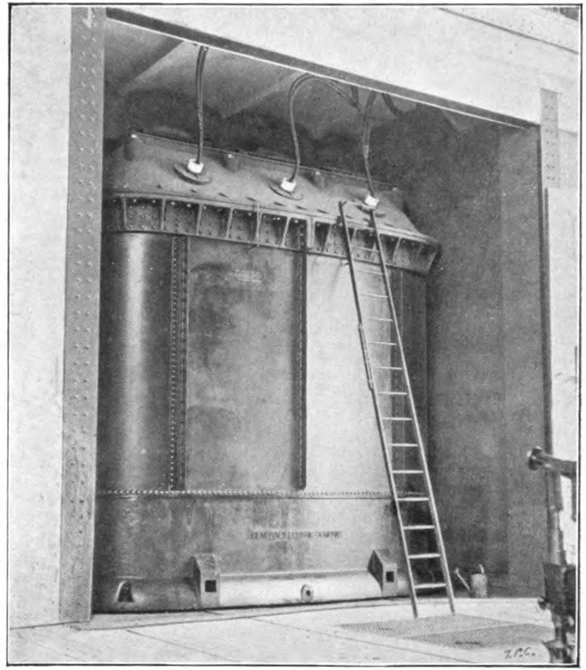

FIG. 10.—10,000 k.w. Transformer, Island Bar.

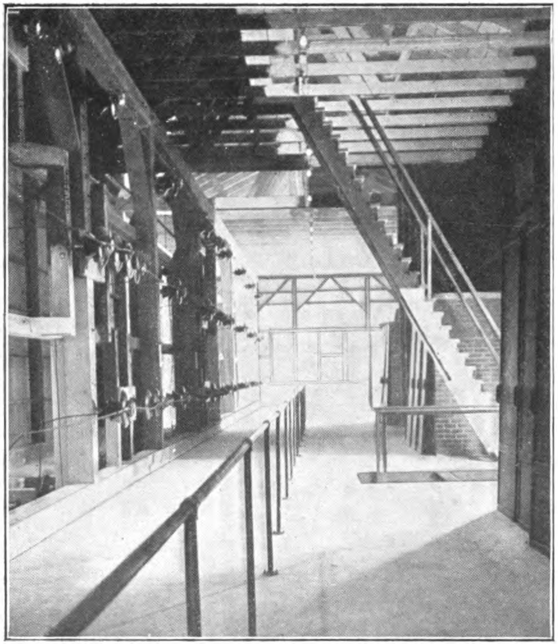

FIG. 11.—Busbars for 60,000 Volts at Electron.

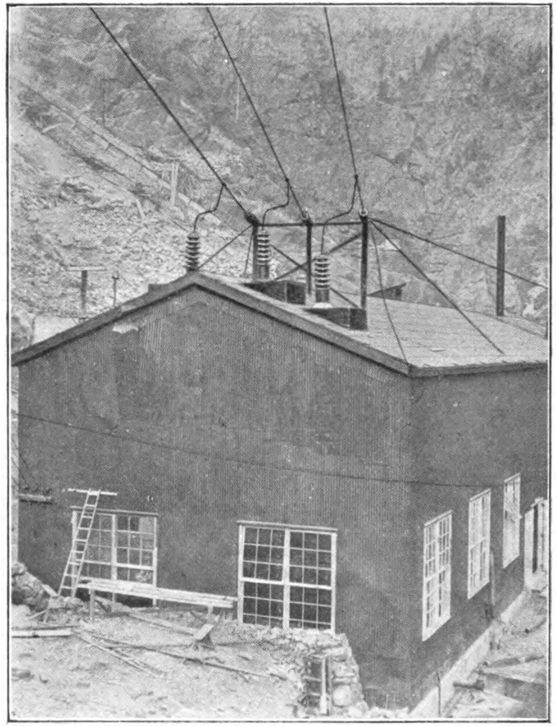

FIG. 12.—Porcelain Bushing for 100,000 Volts in Roof

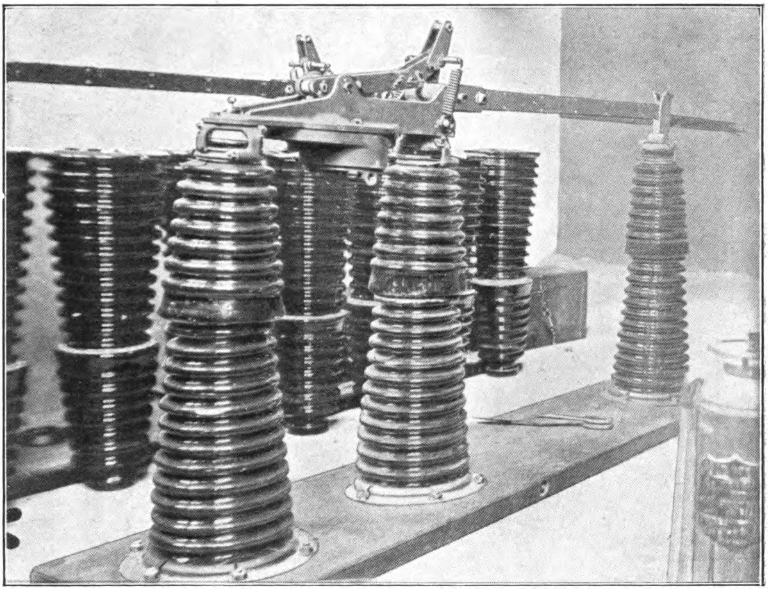

FIG. 13.—Pneumatically Operated Switch (100,000 Volts).

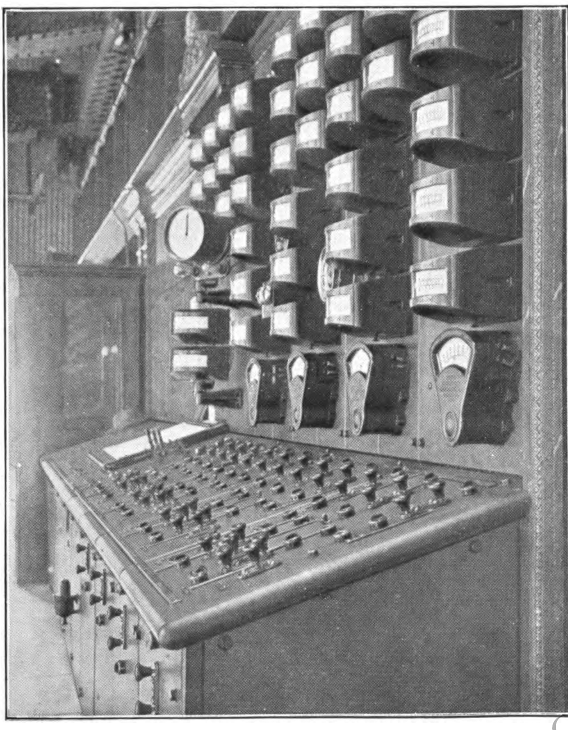

FIG. 14.—Pneumatically Operated Control Board, Island Bar.

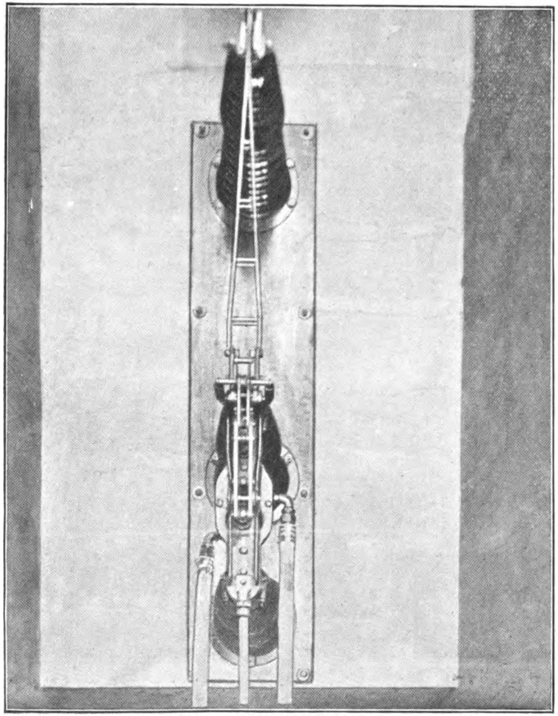

FIG. 15.—Pneumatically Operated Disconnecting Switch.

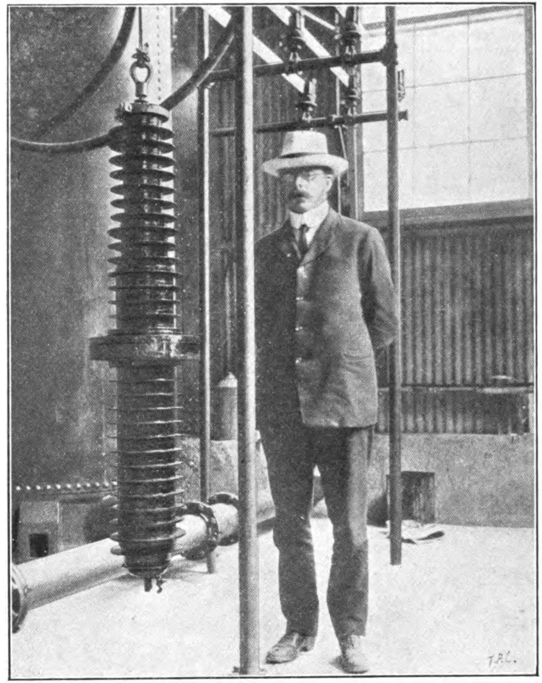

FIG. 16.—Transformer Bushing for 100,000 Volts, Central Colorado Power Company.

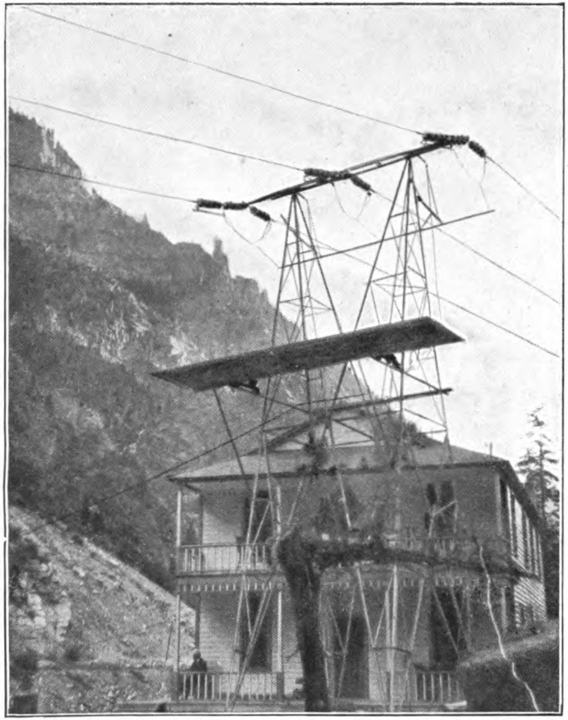

FIG. 19.—Overhead Line for 100,000 Volts, Central Colorado Power Company.

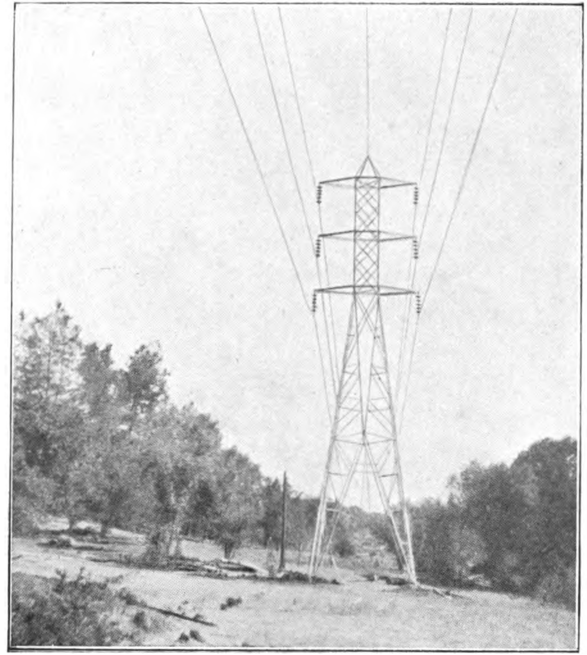

FIG. 20.—Overhead Line, 100,000 Volts, Great Western Power Company.

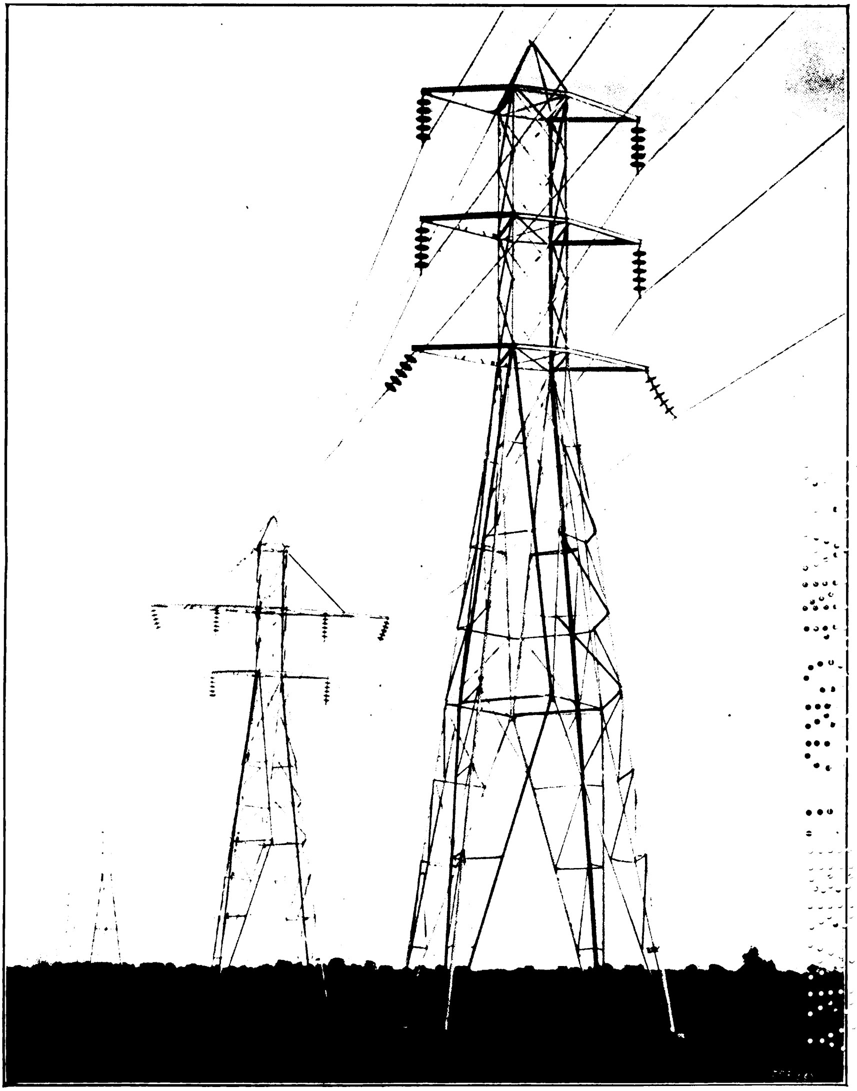

FIG. 21.—Overhead Line for 100,000 Volts, showing Transposing Towers.

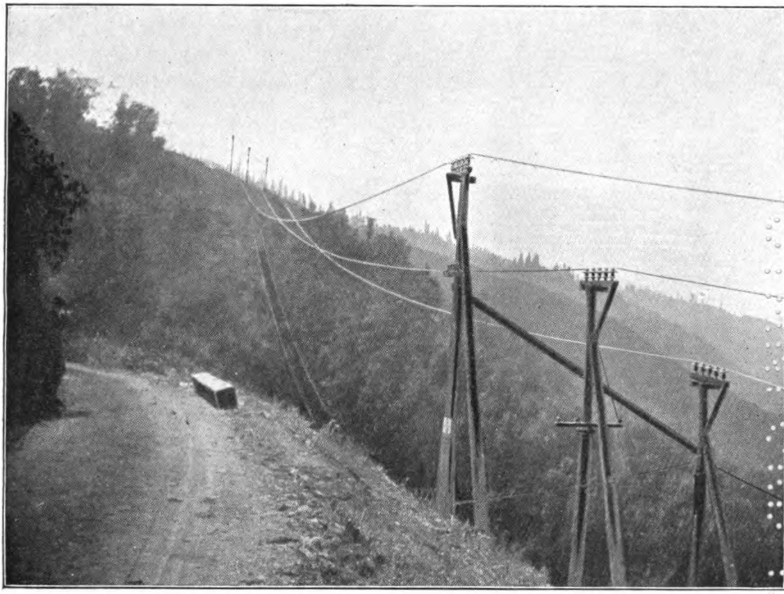

FIG. 24.—Long Span, De Sabla, California.

schemes employ 3-phase alternating current. Though there are certain cases in which direct current would possibly be the more suitable, the ordinary conditions found on the American Continent appear to be better satisfied by the 3-phase alternating-current system.

Undoubtedly for a very long transmission from a remote source of power, such as a waterfall to a large city or industrial area, the Thury system of direct-current transmission has many advantages.

In the first place, the working voltage with a direct-current line may be much higher than that which is possible with an alternating-current one, as the effects which limit the alternating voltage available, such as the corona, depend not upon the R.M.S., but upon the maximum value of the voltage used.

The charging current of the line in an alternating current transmission is a factor needing serious consideration, especially when a frequency of 60 is adopted.

Plant.	Voltage.	Conductor.	Spacing.	Altitude.	Stress.	Factor of Safety.
			Cm.	Feet.	kv./cm.	Allowing for Altitude.
Great Western Power Company, Island Bar	110,000	3·0 B. & S.	300	800	24·2	1·52
	150,000	—	—	—	33·0	1·11
Central Colorado Power Company ...	110,000	7-strand cable, 2·0 B. & S., with hemp core	300	6,000	23·2	1·34
Grand Rapids...	100,000	4·0 B. & S.	300	1,000	19·6	1·87

The possibility of resonance (not really very serious) and the danger of interference with telephone and telegraph circuits also militate against the use of alternating currents.

On the other hand, the elasticity of the alternating-current system, with its parallel method of working, renders it very suitable for the large networks of power lines which are springing up all over the American Continent.

Although it is quite possible that this could be done equally well by the Thury system, it is very doubtful whether any engineer would be justified in installing it in such a case until considerably more experience had been obtained with the existing plants.

It seems very doubtful whether the Thury system will ever be introduced in America, as alternating currents are employed almost universally for everything except railways, and the general conditions governing the supply of electric power are—as is natural to a large, newly settled, and as yet sparsely populated country—very different to those which prevail on the Continent of Europe.

All the installations to be described in this paper use the 3-phase alternating-current system, with, in almost all cases, parallel operation of two or more stations on the same network. In some cases nearly all the power generated was sent to the far end of the line before being used, but in others the station fed into a large distribution system in the neighbourhood.

(*c*) The question of frequency is somewhat akin to that of the choice between direct and alternating currents, and, like it, is settled more by the question of standardisation than by any other consideration. Undoubtedly for any given conditions of length of transmission line, nature of load, and power required, there exists a frequency which will give the best possible results, but which cannot in general be adopted.

The standard frequencies on the American Continent are 25 and 60 ∿, the latter being used almost universally for lighting purposes. It is, however, distinctly too high for a really sound long-distance transmission. In some cases the transmission is at 25 ∿, and frequency changers are employed. Practice, however, seems to vary in different parts of the country, the Niagara plants, for example, all generate at 25 ∿, while 60 ∿ is standard on the Pacific Coast and in most other parts.

There seems to be a great aversion to using 25-∿ current for lighting, although in one or two towns, such as Buffalo, this is done.

The large plants on the Pacific Coast all use 60 ∿, and have very large charging currents. One plant in particular, which will ultimately operate a line 153 miles long at 110,000 volts, will have a charging current corresponding to an output of nearly 15,000 k.v.a. In at least one case, and probably in many, the question of the charging current due to the high frequency has limited the value of the transmission voltage employed. In this case the line is 77 miles long, and the pressure employed 70,000 volts, the charging current corresponding to 3,000 k.v.a. It was stated that, were it not for the high value of the charging current, the voltage would have been taken still higher.

In another case 60-∿ current supplied from a large network is transformed to 25 ∿ for distribution to the rotary converter substations of an electric railway company.

It seems unfortunate that the excessive standardisation prevailing among the manufacturers of electrical machinery should cause the adoption of such an admittedly unsatisfactory frequency as 60 cycles per second. The conditions in America are such that the frequency of generation must also be used for ordinary private lighting, but there is no doubt that quite satisfactory results can be obtained with frequencies much lower than the 60-∿ standard, which would be far more suitable for transmission over long distances.

(*d*) *Parallel Operation.*—The operation of a number of widely distributed central stations on a common distributing network has presented few difficulties in actual practice. The methods adopted for syn-

chronising the machines are similar to those employed in the country, rotary synchronisers being most commonly used. In many cases water-power plants are running in parallel with steam turbines through 100 miles of line, and no difficulty from hunting has been met with.

The latest practice to facilitate good synchronising is by the use of pneumatically controlled switches. These have been installed at the Island Bar station of the Great Western Power Company, and are much quicker in operation than any other form of switch yet put into service. As a matter of fact, the time lag of a switch can always be allowed for by a skilful switchman, but the new switch has the advantage of being independent of the judgment of the operator.

The only phenomenon which is likely to produce hunting with such a system is a short circuit, and on some systems these are of very frequent occurrence. With water turbines and steam turbines there is no cyclic irregularity which could be emphasised by resonance with the period of swing of an alternator. With a large station, having a number of hydroelectric units in parallel there is some risk of hunting, if the units are separately governed and the governors are too quick acting, but this is not so likely to occur with hydroelectric plants as with steam-driven sets. As a matter of fact, synchronising through a long transmission line is a much easier matter than synchronising in a central station. The reactance of each leg of a 60,000-volt line 100 miles long with wires of 000 B. and S. gauge 7-strand cable 6 ft. apart is 34·3 ohms, the resistance 25·6 ohms, giving an impedance of 42·6 ohms. This impedance acts in the same way as the coreless choking coils, which have recently been fitted in some stations to assist synchronising, and cuts down the cross-currents which would otherwise flow when a bad phase is made, to very much smaller dimensions.

The practice of switching-in machines without synchronising is not common in hydroelectric stations, though in the General Electric Company's works at Schenectady synchronous motors and converters are put into circuit in this way, the motors being fitted with copper damping rings to give the necessary starting torque and bring them up to speed.

(*e*) *Line Protection.*—The protection of the overhead line against lightning stroke and atmospheric discharges is a matter of great importance. American engineers state that this problem is one of the most serious that they have to face, and the opinion is very generally held that no so-called lightning arrester is effective in protecting a transmission line against the effect of lightning stroke. The lightning arresters formerly in use were those of the well-known Würts pattern (see Fig. 4) or the carbon rod spark arresters. In nearly every station that was visited, however, both at Niagara and on the Pacific Coast, these arresters are being displaced by those of the electrolytic type (see Fig. 5) recently described by Mr. Peck.* These arresters are kept charged by being connected every other day direct to the overhead line, but normally they are arranged with a

* *Journal of the Institution of Electrical Engineers*, vol. 40, p. 498.

spark-gap between them and the line. Even on a long line arresters are fitted only at the central station and at the sub-stations, the extra safety gained by fitting them at intermediate points being discounted by the increased risk of breakdown due to their use.

The most effective protection against lightning is undoubtedly the earthed wire (see Figs. 20 and 21). During a recent very severe lightning storm near San Francisco, the only transmission line that was not put out of service was one having an earthed wire arranged above the line. Not only does the earthed wire act as a screen against the electrostatic effect by charged clouds moving in the upper regions of the atmosphere, but it also provides a path to earth more direct than that of the line wire over the whole length of the transmission line, and thus prevents a lightning stroke from striking the transmission line. In most cases where the earthed wire is fitted, however, the best practice is to connect a lightning arrester of the ordinary type to the line as an additional safeguard.

Troubles from lightning are much less likely to occur on a high-voltage transmission line than on those working at 20 or 30 kilovolts on account of the more effective insulation of the line.

In no stations are there installed water-jet dischargers in which an electrostatic charge is conveyed to earth through a water jet playing against the line. With the high voltage used, it is obvious that the resistance of the water, if there is to be no considerable leakage current, would have to be so high that it would not be sufficiently conducting to get rid of an electrostatic charge with any great rapidity.

(*f*) *Asynchronous Generators.*—It has been suggested at various times that asynchronous generators consisting of ordinary induction motors run above synchronous speed could, with advantage, be employed in many transmission systems. This is especially the case in large networks fed from a number of stations. On some of these networks where there are many small water-powers the use of such a small generator has many advantages. It is extremely robust and mechanical in construction, and quite simple in operation; it needs no exciter and has no rubbing contacts. It can be thrown straight on to the line without synchronising and it can be short-circuited with impunity. It requires, of course, that the current at the station shall lead on the voltage in order to supply the necessary magnetising component. This is not generally a disadvantage, as on all high-tension long-distance transmission lines the heavy charging current will look after this. An asynchronous generator connected to a line of sufficient capacity will excite itself and furnish power without the use of any synchronous machine to set the step, and on this account care should be taken that the magnetic circuit of such a machine is not worked at too low a density.

Asynchronous stations feeding into networks generally have their governors arranged so that they work steadily at full load all the time. The variable portion of the load is taken care of by ordinary synchronous generators driven by water-wheels, or sometimes by steam turbines.

An interesting example of the use of asynchronous machines is given by the exciter sets in many of the generating stations of the Pacific Gas and Electric Company. In these sets a water-turbine or Pelton wheel, a direct-current generator, and an induction motor are all coupled together. In case of a heavy load on the generator, the induction motor helps the water-wheel, while, if the load is light, power is returned to the line by the induction motor running as generator. No governors are provided, the speed being controlled entirely by the induction motor. Synchronous machines had been tried, but had given trouble by breaking step.

The possibilities of asynchronous machines, and their advantages in many cases over generators of the ordinary type, are recognised by some of the leading engineers of the large American systems.

(*g*) *Telephone Interference.*—An efficient system of telephones is a matter of fundamental importance in the operation of a large network, and the question of telephone interference is therefore one which requires most careful consideration. In the case of a transmission line at 100,000 volts and over, no attempt appears to have been made to run the telephone lines on the same pole as those that are used for the transmission line. With 60,000-volt schemes the usual practice is to arrange the telephone line about 10 ft. below the transmission line, and to support it on insulators on the same poles. In order to avoid mutual induction effects, the telephone lines are transposed at frequent intervals. Transposition of the telephone line is, however, not sufficient to prevent induction, as the inductive effect from the three main lines are sufficiently different in magnitude on the two telephone lines to give large currents along the whole length of line. Electromagnetic induction may be almost completely avoided by transposing both the transmission line and the telephone line. The transposition of the transmission line is effected by using special pairs of towers at intervals of about 3 miles (see Fig. 21). With these precautions the telephone is sufficiently satisfactory, even over a line of 150 miles in length.

If the neutral-point of the 3-phase system is earthed, this arrangement serves as an efficient safeguard against electrostatic effects, but where Δ-connected transformers are used, and there is no definite earth-point provided, these effects may be very large.

In order to obviate them as far as possible at the telephone, the wires are connected by a split-choking coil at the ends of the line, and the centre-point of this coil is connected to earth.

In most of the large installations the telephones are brought to a controlling station, from which all instructions as to the operation of the various plants are issued by a "load dispatcher." The "load dispatcher" gives instructions to each plant as to the number of units which are required to be in operation at the station; all breakdowns of the line are reported to him, so that he knows exactly what sources of power are available for the supply that is required.

(*h*) *Star* v. Δ *Connection.*—The arrangement of the transformer on

the high-tension network is one in which considerable discrepancy of practice appears to exist. At the present time there seems to be a decided preference in favour of Δ connection. Briefly stated, the relative advantages of the two methods of connection are as follows:—

Advantages of Δ: (1) If one of the phases break down the other two will supply power to the extent of two-thirds of the capacity of the transformer; (2) if an earth occur on one leg of the transmission line it does not affect the running of the system provided the insulators on the other two wires are sufficiently large to stand the concatenated pressure of the system.

Advantages of Star: (1) The size of insulator used need only be large enough to withstand the star pressure of the system; (2) the neutral-point can be earthed and the pressure between each line and earth definitely equalised.

(This point is of great importance in connection with telephones, as mentioned above.)

As a matter of fact, the advantages of the Δ system in enabling the transformer to run with two phases only, if one of the lines break down, is not practically important, as it is found with 60,000-volt working that the insulators installed are rarely large enough to withstand the full-line pressure, and if one of the phases break down the line is put out of service until repairs are effected. The same thing holds good with regard to the transformers. In spite of this, however, Δ connection is much more common than star, and at the Great Western Power Company's station, where the change from 60,000 to 110,000 was made on October 1, 1909, the connection was altered at the same time from star to Δ. No practical difficulty of overheating due to circulating triple frequency current appears to be met with in this arrangement, nor does the variability of the neutral-point appear to have any prejudicial effect on the working of the system.

It is remarkable that star working is not more frequently used, as it would appear to be a much more satisfactory arrangement from almost every point of view on extra high-tension systems.

Economic Limits of Transmission.

The factors which determine whether a given water-power can be used economically for the supply of electrical energy are: (1) The capital cost of the transmission scheme; (2) the running charge of the station; (3) the cost of producing energy by other means. The last factor is, of course, simply a basis for comparison. If fuel is expensive—as it is on the Pacific Slope—then, obviously, it is economically practicable to use water-powers involving much higher capital expenditure than in a country where coal is very cheap. The capital charges in connection with hydroelectric schemes are by far the most important in determining the cost of generating energy. The running charges are invariably low. In the Ontario Power Company's station at Niagara, the whole plant of 50,000 k.w. was in charge of three men

and two switchboard operators. In some stations the labour required is much greater. For example, at the Electron station, where a wooden flume 10 miles long is used to convey the water of the Puyallup River to the station reservoir, a staff of 50 men was employed in keeping the flume in a proper state of repair. This latter case is, however, quite exceptional, and it is probable that in a very short time all work of a temporary character on hydroelectric stations will be replaced by structures of a more permanent nature. The chief item in the cost of hydroelectric power production is, therefore, the capital charge, and in such a station this is almost invariably higher than for a steam plant. The stations in which one would expect the greatest economy in capital expenditure would be those at Niagara, where the problem of conveying the water to the station only involves the boring of a short tunnel, and where the plant capacity is large. In these stations, however, the cost was given at from £20 to £30 per kilowatt, including the transmission line, though in some cases it was a good deal higher. The higher figure is for the older stations, where a large amount of excavation work had to be done, and where a very expensive type of machine with a shaft 130 ft. long between turbine and generator had been installed. The lowest figure for capital expenditure was given for a station with a very small head, in which the natural conditions at the station involved a very small outlay in providing a channel for the water to reach the penstock. The cost of this station, including transmission line, was only £15 per kilowatt. Besides the capital charge involved in the station itself, the charge for the transmission line is usually a very serious matter. The Ontario Electric Development Company, for example, sell their energy at Niagara for less than half of what they charge for it at Toronto.

One of the most interesting points about the transmission line is the determination of the most economical voltage at which it should be worked. Kelvin's Law states that the most economical section of conductor for a given transmission is that for which the capital charge on that portion of the capital expenditure which is proportional to the area of the conductor shall be equal to the annual cost of wasted energy.

Kelvin's Law is based on the condition that the total charge for transmitting energy along the line shall be a minimum, but a sounder condition to apply to a transmission line is that the ratio of the total cost of transmitting energy to the revenue earned shall be a minimum, and if this condition is applied we find that the cost of wasted energy must be equal to the whole charge for interest and depreciation on the transmission line. If we assume a cost for the station of £30 per kilowatt, a load factor of 50 per cent., and interest and depreciation charges 12½ per cent., the cost per B.T.U. will be 0·206d. The total cost per B.T.U. will amount to not more than 0·25d. On a 150 mile 20,000-k.w. transmission allowing 10 per cent. copper drop the cost of waste energy will correspond with a capital charge of £120,000, if 15 per cent. is allowed for interest and depreciation on the line, or a capital charge of £800 per mile. The cost of poles and insulators on a 50,000-volt line will be about

£200 per mile, and the balance will pay for a 3-wire line, each conductor of which is 0·30 sq. in. in area. This corresponds fairly closely with the actual section necessary to give a 10 per cent. drop, *i.e.*, 0·35 sq. in. of copper. The calculation shows that the use of these voltages is economically sound, and that for transmissions of 200 miles and over pressures of the order of 100,000 volts must be employed.

The second factor which determines the size of the conductor is the working pressure. With the high pressures used (as is shown above) the possibilities of the formation of a corona and the loss of considerable energy by brush discharge is one that requires careful consideration, and it would be impossible to reduce the section of the conductor used for the transmission below that for which such effects are produced. Another factor which might be expected to have some influence on the choice of voltage used for transmission is the cost of insulating the line. The cost of insulation goes up very rapidly when the voltage is greatly increased. The cost of insulators for a line designed to work at 100,000 volts is more than double that for a line designed for 60,000 volts, and it is a matter of simple arithmetic to determine in any particular case what is the most economical voltage for any given transmission scheme. In actual practice the effect of increasing voltage on the cost of insulation is not of great moment, as the cost of insulators is a comparatively small item in the total cost of a pole-line, and the working voltage is settled by the economic considerations detailed above. The common practice is to work the line to give a predetermined voltage drop, and to increase the voltage on the line as the load on it increases until at the full load the pressure on the line is the maximum for which it was designed. The usual efficiency of transmission on most of the schemes seems to be about 90 per cent., the copper drop being of the order of 10 per cent., and the total drop due to resistance and inductance about 15 per cent.

Modern Practice (Hydroelectric Plants Only).

The Station Itself.—The design of a hydroelectric power station is affected by local conditions to a much greater extent than if any other form of motive power were employed. Every hydraulic station, in fact, presents a distinct problem of its own, and has far more interest for the engineer than the ordinary power station built in England, which contains so many standard turbo-generator sets, combined with a certain number of equally standard boilers.

The nature of the country, the height of fall available, the nature of rock in the vicinity, and the geographical configuration of the country, all have to be considered in planning out a station and its transmission line. In some favoured cases, such as Niagara and the Snoqualmie Falls, which supply Seattle and the Puget Sound district, an actual waterfall has been found ready to hand, and no flumes or pipe-lines are required, beyond the pipes or tunnels necessary to carry the water from the top of the Falls to the turbines at the foot. This, however, is

rather the exception than the rule, and in many cases long lengths of flume, pipe, or tunnel have been necessary; especially is this the case in the western and central districts of America, where actual waterfalls are rare, but rocky canyons containing rushing rivers are of frequent occurrence.

The means adopted in this case of leading the water to the turbines from the higher reaches of the river depend entirely on local conditions. In some cases, notably at the Island Bar Station of the Great Western Power Company, the river follows such a winding course that a short tunnel driven through a mountain will tap the stream many miles further along its course. In this particular case a tunnel 3 miles long reaches a point on the river 18 miles higher up along its valley, and a head of 420 ft. is secured, which will ultimately be increased to 520 ft. by building a dam and flooding the ravine. At the station at Vancouver also a tunnel 2½ miles has been constructed, which takes water from a neighbouring lake in another valley, and so increases greatly the power available.

In many cases, however, this construction is not practicable, and long flumes, ditches, or pipe-lines have been constructed along the sides of the valley. These flumes are generally built of wood, although the use of reinforced concrete is now being considered, as the life of a wooden one only averages about five years, and the flume requires constant watching and patrolling.

The flume generally ends in a small storage reservoir sufficient to run the station for a few hours, from which steel pipes lead to the turbines. The storage has to be sufficient to keep the station running, while any necessary repairs are made to the flume.

In some cases the flume is replaced by a pipe-line, frequently constructed of wood. An example of this is found at the power station at Ogden Utah, where a wooden pipe 6 miles long is employed (see Fig. 6).

In at least one plant—viz., that of the Central Colorado Power Company, at Shoshone, Colorado—the flume is replaced by a tunnel cut in the rocky wall which forms the side of the valley.

Pressure tunnels are occasionally found, but in most cases the water flows along the tunnel at the hydraulic gradient. If a pressure tunnel is employed some protective device has to be installed to guard against the effects of water hammer.

The choice of prime mover adopted depends very much upon the head of water available. Pelton or Doble wheels (see Fig. 7) are generally used on high heads of 500 ft. and over, and reaction turbines on the lower ones. Pelton or Doble wheels are invariably installed with horizontal shafts, but turbines are used with either vertical or horizontal ones, although the vertical shaft type is the most favoured at the present time. An interesting example of a low head turbine plant will be seen in the new power station for the City of Winnipeg, where the turbines are in a separate room to the generators and work entirely drowned in water—the dividing wall being built as a dam, and

the shaft passing through a stuffing-box in it. The head of this plant is only 40 ft.

The chief disadvantage of the vertical shaft turbine is the amount of excavation involved in the construction of the wheel-pit, this being especially noticeable in the well-known plants at Niagara, which, with one exception, have their generators situated at the top of the falls while the turbines are, of course, at the bottom. Out of five large stations at this centre one only—viz., that of the Ontario Power Company—has its machines at the same level as the turbines. The most striking example of excavation is, however, found at the Snoqualmie Falls, where a chamber 200 ft. by 40 ft. by 30 ft. at a depth of 260 ft. below the ground has been cut out of the solid rock, although horizontal shaft turbines have been adopted.

Closely connected with the question of head and type of turbine is that of safety devices, including governing. The problem of satisfactorily governing a large station working under a high head is a very difficult one, and great care must be taken to protect the pipe-line from the effects of water hammer or stress due to the load being suddenly thrown off. There have been cases of stations having their pipe-lines completely wrecked by the sudden closing of a valve at the lower end.

The chief function of the governor in a hydraulic station as generally installed in the western and central States is to prevent the machines from running away if the whole load is suddenly thrown off. During normal operation it is common practice to keep the machines running at full load and look after the variations by means of a steam plant installed at some other point on the system.

If governing is effected by checking the flow of water it is necessary to have some form of relief valve or surge pipe installed, a surge pipe (see Fig. 8) being probably the most satisfactory if the head is not too great. A common practice is to use some form of relay valve operated by the water pressure and controlling an oil or hydraulic cylinder which operates the relief valve proper.

The pressure tunnel at the plant of the Great Western Power Company is protected by a surge pipe at its junction with the steel pipe-line in addition to the usual relief valves at the station itself. That there is need for a protection of this sort was manifest by the frequency with which it discharged and the large volume of water which escaped at each discharge.

With high head plants using Pelton or Doble wheels governing is almost invariably obtained by swinging the nozzles so as to partially clear the buckets. These plants are generally placed longitudinally beside a stream and the nozzles arranged to discharge into it. This method of governing, although obviously very wasteful of water, relieves the pipes from all stress and on the very high head plants of 1,000 ft. or over is universal.

So difficult is the problem of satisfactory governing that on some of the older plants arrangements are installed for putting on artificial load

in order to keep the total draught on the station steady. One plant at least appeared to do this by hand. Another one used a water load, the plates of which were raised and lowered by oil pressure, the admission of oil being controlled by a relay valve actuated by the governor (see Fig. 9). This had replaced the original hydraulic governor on the turbine, which was unsatisfactory below one-third load. In the case of Pelton wheels driving exciters and fed off the main pipe-line, spear rod governing is employed as the quantity of water used is only small. An interesting safety device was seen in a small (300-k.w.) station at Cornell University, where the water was allowed to compress a column of air in a steel cylinder which thus acted as a buffer.

The general arrangement of the plant of a modern station is fairly well standardised although not to anything like the extent of an English steam-driven station. General practice in the most recent stations appears to favour generation at about 11,000 volts with oil-insulated water-cooled transformers of large capacity raising the pressure to that of the line. Taps are frequently provided for working at less then the full voltage, if desired, and this is often done during the early stages of the plant, before it gets its full load. In some cases the transformer is considered as forming one unit with its generating plant, as in the plant of the Great Western Power Company, where each machine has its own 3-phase transformer of 10,000-k.w. capacity (see Fig. 10). In one case —viz., the plant of the Central Colorado Power Company—the transformers were treated as forming part of the line, a bank of three single-phase transformers being connected thereto without any high-tension switchgear at all; this, however, is not usually the case, high-tension oil and disconnecting switches being extensively used.

The hydraulic portion of the plant depends naturally very much on local conditions, but where these are similar a standardised design has been adopted. This is especially the case with the vertical shaft pattern, as found in a large number of medium head stations. The oil supply of such a plant is a matter demanding considerable care, as the consequence of a failure of the pressure oil to the footstep bearings of the turbine would be disastrous. The oil supply for this is generally furnished by separate pumps to those which supply the governing mechanism, but provision is made for each supply to draw on the other in case of need.

In only one case were direct-coupled exciters found. Separate machines driven by small turbines or Pelton wheels are practically universal.

Considerable diversity exists in the design of the switchgear, both cell type and open-pattern arrangement being found, the numbers of each being about equally divided if the Niagara plants are included.

If these are left out, the majority of the stations visited had their high-tension gear and busbars quite exposed (see Fig. 11), although neighbouring parts were generally separated by brick partitions. Copper or aluminium rods supported on large pin-type insulators were used in all the plants except that of the Central Colorado Company,

where the rods were hung from above by means of suspension insulators such as were employed on the line.

The line is usually brought into the station through large porcelain bushings, sometimes set in the station wall, but in the higher voltage plants placed in the roof, in which case they much resemble a large transformer bushing (see Fig. 12). Just outside the station are placed the lightning arresters (see line protection).

Inside the station the line goes to a choking coil, usually a plain copper spiral hung in the air, but sometimes an elaborate piece of apparatus with oil insulation. In all cases but one the line was fed through oil and disconnecting switches from the high-tension "bus." The oil switches are either mechanically, electrically, or pneumatically operated, the last named being used on the 110,000-volt plant of the Great Western Power Company, where they appear to be giving satisfaction (see Fig. 14). The whole of the switch, including the operating cylinder, is alive, and air is supplied through rubber insulating hose. Consequently the switch is extremely compact and takes up but little space considering the high voltage at which it works.

The disconnecting switches are usually plain knife switches, opened by hand by means of a wooden rod about 8 ft. long. The insulation of this rod is quite sufficient to allow the user to touch live parts with perfect safety, although in the case of the Great Western Power Company the disconnecting switches, like the oil switches, are pneumatically operated (see Figs. 13 and 15).

Instrument transformers are frequently employed on the high-tension side of the station. Small electrostatic potential indicators are used on the high-tension conductors to indicate to the operators whether these are alive or not. They consist simply of a pivoted aluminium vane moving in front of a fixed section and acting on a similar principle to an ordinary electroscope.

The generators employed in modern stations are all revolving-pole machines of fairly high speed, a 10,000-k.w. machine generally running about 300 revs. per minute. Their construction is therefore intermediate between that of an ordinary slow-speed machine and a high-speed turbo-generator. Salient-pole rotors and natural ventilation seem to be universal.

Both 3-phase transformers and banks of single-phase units are employed, and practice does not seem to be decided as to which of these is the best. In a small station where there is only one bank of transformers, single-phase units have the advantage that less spare capacity need be carried, while in large stations with a number of banks the provision of a complete bank in the shape of one 3-phase transformer is not a serious matter. In the small station, on the other hand, this would involve carrying a spare plant of capacity equal to that installed, while with three single-phase units only one-third of the working capacity would be necessary.

Air-cooled and insulated transformers are used in some of the older

stations working at 40,000 volts and under, but not in any of the newer or very high-voltage plants, and they need not be seriously considered. The fire risk from oil insulation does not appear to be great, although it is usual to place each transformer in a separate brick chamber with a steel door that can be closed if required.

The insulation of the high-tension leads where they pass through the case of the transformer is a most difficult problem. A terminal for 100,000 volts is quite a large thing, even if condenser-type insulation be adopted (see Fig. 16).

The object of the so-called condenser-type insulation is to obtain a terminal over the surface of the insulation of which the potential gradient shall be nearly as possible uniform. This is done by embedding in the insulating material metal laminæ whose dimensions are so chosen that the capacity between any two laminæ is the same, thus giving a number of equal increments of potential from the case of the transformer to the live conductor.

Line Construction.—With the exception of a 33,000-volt line feeding Schenectady, all plants in the States working at less than 65,000 volts appear to use pin insulators, while above this the suspension type is employed.

The construction of the pin insulator depends, of course, upon the voltage for which it is designed, but on 60,000 volts 3- or 4-part insulators are usual.

Brown porcelain is very general, but a slate-coloured glaze is now being introduced, which is said to give a very inconspicuous insulator. White glazed porcelain is never used, the reason given by the makers being that it makes too good a target for rifle bullets, although inquiries made at the various power plants showed but little trouble on this score.

Glass insulators, practically universal on telephone and 2,300-volt lighting circuits, are not used on the highest voltage lines. They were originally employed at Vancouver on 40,000 volts, but are being replaced by brown porcelain. Lack of mechanical strength and liability to cracking by the action of frost seem to be their chief disadvantages.

Suspension insulators and steel towers are the latest development in line construction, and are always used for the very high voltages—*i.e.*, 100,000 volts or over. There are two types of suspension insulators in common use, viz., the Locke and the General Electric patterns (Figs. 17 and 18).

These are generally used either four or five in series on a 100,000-volt line, which gives ample insulation, even if one insulator should break down. They are hung from the cross-arms, and no provision made against the swinging of the conductor except that anchor towers and strain insulators are installed at intervals and, of course, at all bends in the line.

With suspension insulators the ordinary triangular arrangement of conductors is not, of course, practicable; generally if only one line is

installed the three conductors are placed in one horizontal plane as seen in Fig. 19. When two lines are run, three conductors can be placed on each side of the tower and suspended from three cross-arms as in Fig. 20.

The towers are generally galvanised steel, shipped in sections which are bolted together at the site. Each section is galvanised completely after construction, so that the risk of corrosion is very slight. It is usual to test insulators to at least 50 per cent. above their working

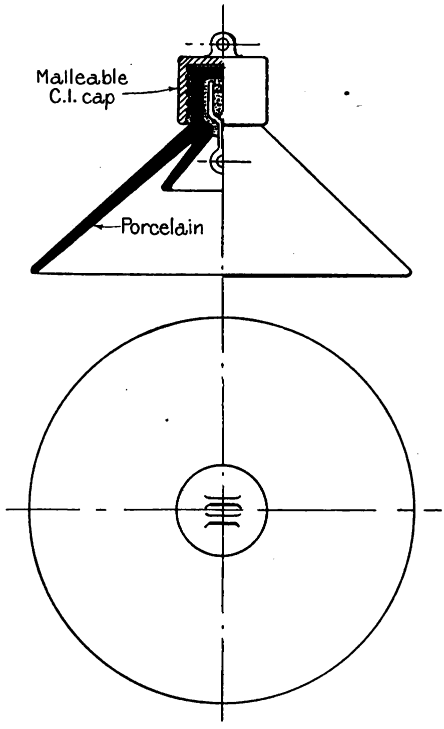

FIG. 17.—Locke Pattern Suspension Insulation.

pressure before leaving the works. Firms which undertake the manufacture of insulators have installed elaborate testing equipments for this purpose, with which a considerable amount of original work has been carried out.

Although America has been regarded as the home of wooden poles, all the latest and best plants, both at Niagara and in the western and central districts, are now adopting galvanised steel. The advantages of these are fairly obvious, as they are much stronger and more reliable than wood, and also have a longer life. Creosoted wooden poles seem

unknown in either Canada or the States, and the life of an untreated pole is generally short. Moreover timber, especially good quality stuff such as is required for transmission work, is getting steadily scarcer, while the steel industry of the country is rapidly expanding.

The effect of climate on the formation of a corona on the transmission line has already been noticed. It also has a considerable bearing on the size and type of insulator employed. For example, at the De Sabla station of the Pacific Gas and Electric Company 11-in. insulators of the type shown in Fig. 22 were used in the interior of the country,

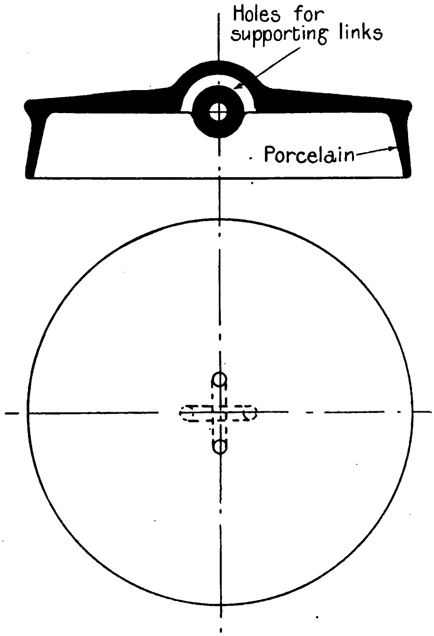

FIG. 18.—General Electric Suspension Insulation.

while on the same system 14-in. triple petticoat insulators, similar to Fig. 23, were employed near the sea coast owing to the effect of salt sea-fogs, which are frequent in the San Francisco region.

Again, in the lines running in the neighbourhood of the Great Alkali desert of America, frequent trouble is caused by dust-storms, which deposit the salt dust on the insulators and cause short circuits.

Heavy rains of the kind which occur on the Pacific Coast in the winter season do little harm, and keep the insulators clean. The only kind of precipitation to be feared is that which takes the form of a driving mist or drizzle. It is not certain whether any serious loss takes place off a line owing to the proximity of forest fires. In some parts

of the north-west during the latter part of the summer the air is so thick with smoke from burning timber (chiefly due to the clearing of land by settlers) that it is impossible to see more than a mile or so. Laboratory tests have shown a marked loss under these conditions, but none of the stations reported any inconvenience arising from this cause. Snow and sleet occasionally cause trouble, more especially in the eastern parts of Canada and the States. On the western slope cold weather is rarely experienced, and the central States, although very cold, have but little snow.

Instances occur every winter of eastern districts being shut down for periods which would be thought excessive in England; but the American public seem to appreciate that it is better to have light ninety-nine days out of a hundred than to have no light at all. Certainly with the American system of transmission and distribution electricity is

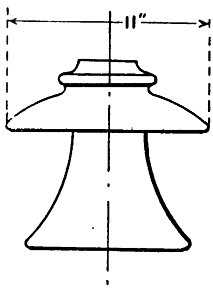

FIG. 22.—Type of Insulator used in Mountains—Pacific Gas and Electric Company.

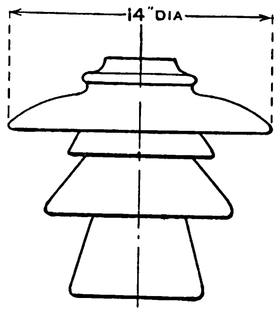

FIG. 23.—Large Insulator used near Coast—Pacific Gas and Electric Company.

available in places in which it could never be obtained under our conditions.

Wooden v. *Iron Pins for Insulators.*—In all the early installations the insulators were mounted on wooden pins, usually of eucalyptus-wood soaked in oil or boiled in paraffin. The two difficulties which have arisen in connection with these are: (1) The digesting of the pin-screw due presumably to the formation of nitrogen compounds by brush discharges from the wire; (2) burning of pins due to leakage current. Of these two phenomena the first is by far the most prevalent, particularly on the Pacific Coast, and has led to the practical abandonment of the use of this type of pin in all newer installations. Even in the Salt Lake District at Ogden, where the transmission pressure is only 28,000 volts, the wooden pins are being steadily displaced by iron pins, either with lead screws for screwing into the insulators or by iron pins cemented into the insulators.

The phenomenon of the digestion of the pin is a very interesting one—the wood becomes powdery in character, and entirely loses its

mechanical strength. The digestion appears only to take place after the oil has exuded from the pins, and does not give much trouble until the pin has been in service for some years. The phenomenon of pin-burning is much less common; a few examples of burnt pins occur, but it is difficult to see how sufficient energy can be passed through the pin unless an insulator is broken or a heavy fog prevails. The trouble occurs most in the neighbourhood of San Francisco, where fogs are prevalent at certain times of the year. The iron pin insulator is now universally employed in new installations, and must be regarded as standard practice. Little difficulty appears to occur on account of corrosion, even in the damp climate of British Columbia, if the pins are well galvanised. The mounting of the pin is effected by three methods: (1) A lead cap is attached to one end of the pin, and this is screwed into the insulator; (2) an iron thimble, or sleeve, with the inside screwed, is cemented into the insulator, and the pin is screwed into this when the insulator is attached. The advantage of these two methods of attaching the insulator are that it is very easily replaced in case of breakdown, as a linesman can easily screw on a fresh insulator if he finds one broken. The third method of attaching the insulator is to cement the iron pin direct into the insulator cap. By this means a very sound job is effected, but the insulator is not so readily replaceable as it is if the other two methods of construction are adopted. The difficulty of transportation is increased if the pins are mounted in this way. In some new types of pins a porcelain base is attached to the pin, the upper end being finished by a wood thimble, which is screwed into the insulator. This porcelain base really provides an additional petticoat for the insulator, and protects the pin from the effects of the weather.

Length of Span.—With a wooden pole-line the length of span is usually from 120 to 150 ft., but with a steel tower construction the length of span is increased, on account of the greater strength of the towers, and it is no unusual thing with such a line to have as long a span as 800 ft. for the normal line. Where a canyon or strait has to be crossed spans as long as 3,000 ft. are installed, but in this case steel wire is used instead of aluminium or copper.

It might be expected that with such long spans there would be more danger of the wires swinging together in a high wind, but as a matter of fact this difficulty does not seem to be a serious one. The wires oscillate very little when they are deflected by the wind and swing in unison. The clearances are, of course, much larger than with the lower voltages and shorter spans. The normal clearance on a 60,000-volt line is 6 ft., on a 100,000-volt line 10 ft., and in the latter case, at Island Bar, the three transmission lines are arranged one above the other, so that there is practically no risk of their touching. The sag of a line with a long span is, of course, much larger than with a shorter span; for a given tension on the line the sag increases in proportion to the square of the distance between the supports, and this necessitates the use of much higher towers. At the Great Western

Power Company's installation the height of tower was 90 ft., while in Central Colorado, where the number of poles per mile is 6, the height of the tower is only 50 ft. The sag allowed may be very large, as much as 30 or 40 ft., at the highest temperatures.

Where the transmission line crosses a railroad or road the usual practice is to arrange two towers as near together as possible on each side, so that a wire breaking will not be able to reach the ground. A cage such as is common in England is rarely if ever seen, and in some parts no special precaution is taken against risk from falling wires.

Line Material.—The two metals chiefly used for an overhead line are aluminium and copper. The relative advantages of these have been much discussed, and although a great many lines have been erected with aluminium as the conducting material, the tendency in the newer stations, at any rate on the Pacific Coast, is to use copper. The advantages of copper are that it has great mechanical strength, and is a material which is easily jointed and soldered; it is not so electro-positive as aluminium, and is therefore not so likely to corrode in a foggy atmosphere. On the other hand, aluminium has the advantage of being a lighter metal than copper for the same conductivity, and is a less expensive material to erect. Joints in an aluminium cable are usually made by splicing, no solder being used to give better conductivity. These long splices are often made in the middle of long spans, and appear to be quite satisfactory. The conductor used is, in nearly every case, a stranded one. This is necessary for heavy current transmissions, on account of the great stiffness of a solid conductor. Even when stranded with seven or nineteen wires the cable is often too stiff for convenient handling, and a hemp core is inserted. Another reason for the use of the hemp core is that when a 7-strand cable is erected in the ordinary way, it is usually the centre strand which breaks when the cable is strained. By having the conductors regularly arranged around a central core the stress is more uniformly distributed, and the cable has greater strength for a given cross-section of material than if it were built up in the ordinary way. One disadvantage of aluminium is that it has a higher coefficient of expansion than copper.

Coefficient of expansion of	copper	per °F.	...	0·0000096
„ „	aluminium	„	...	0·0000128
„ „	steel	„	...	0·0000064

Hence an aluminium line will change in sag more with increase in temperature than one of copper, and when the sag becomes comparable with the height of the tower this is a matter of some importance.

A disadvantage of the larger cross-section of the aluminium line is that the effect of wind pressure on it is more marked than on a copper line, but, on the other hand, the risk of a corona effect and brush dis-

charge with an aluminium line is considerably lessened. The third material which is sometimes used is steel, but this is employed only on long spans where the question of mechanical strength is of primary importance. Steel can, of course, be worked at a much higher stress than either copper or aluminium, and in spite of its relatively high resistance, is used on all very long spans of 3,000 ft. or over.

SUB-STATIONS.

(*a*) *Static Transformers*.—The general distribution system in America is so different to that of England that a few words of explanation may be tendered in order to show what special problems are presented in that country.

Direct-current distribution as found here is unknown except in one or two of the largest towns, and then only in the central districts. The chief use of direct current is for railway work, and to some extent for elevator service.

The universal system of distribution is by means of overhead wires strung on wooden poles and working at 2,300 volts; these are carried along all the streets. At intervals a small transformer is bolted on the pole, and steps the pressure down to 110 volts for service to the neighbouring houses. In consequence of this there are a large number of sub-stations which simply contain static transformers for reducing the pressure to the 2,300 volts required for distribution.

These stations, in addition to the transformers themselves, contain induction regulators for regulating the voltage on the outgoing side. These are constructed like an ordinary induction motor with a stator connected as a shunt across the lines and a wound rotor which is prevented from rotating, but can be turned through an angle by means of a quadrant gearing with a worm driven by a small motor. The axis of the regulator is placed vertically, and the whole apparatus, except the quadrant and motor, are immersed in oil. Automatic regulation is thus obtained by adding or subtracting the regulation voltage from that of the line.

In some of the sub-stations of the Pacific Gas and Electric Company regulation was obtained by the use of tapping points on the transformers. A number of turns of the winding equal to 5 per cent. of the whole amount were brought out and subdivided to give steps of about 1 per cent. each.

A selector switch was arranged to take current off any one, and their connection could also be reversed so as to give a total range of 10 per cent. These regulators were worked by hand and appeared to give satisfaction. They have the advantage over the induction regulators of not affecting the power factor of the line, though this is not a very serious drawback when the regulation required is only small.

In some towns the 60,000-volt current is stepped down to 12,000 volts or so before entering the city. This may be done from a desire

to safeguard the citizens, but it is more likely owing to the fact that 60,000-volt transformers can only be built in large sizes and that 2,300 volts is not sufficient to feed a very large area.

Underground cables are used occasionally in the busier districts of the large cities, but are, generally speaking, very uncommon.

(*b*) *Sub-stations Converting from Alternating to Direct Current.*—These are chiefly used for railway work, but also for city supply and series arc lighting.

The machinery installed presents no special interest, both synchronous and induction motor-generators and rotary converters being found, but the motor converter does not appear to be used. Rotary converters are used on 60 cycles up to quite large sizes, an example being a 2,000-k.w. machine installed at Vancouver. This, however, is an exceptional size, and machines for this frequency are not common above 500 k.w.

Vertical shaft machines are found in some stations, an interesting example being some rotary converters now being built in which the shaft is stationary and the armature spins on it as a pivot.

Stations supplying current for series arc lighting are peculiar to the American continent, quite high voltages (up to 10,000 volts) being employed. Rotating machinery is sometimes used to effect the conversion, but extensive use is also made of mercury vapour rectifiers combined with constant-current transformers. These rectifiers appear to be very successful, having a life of 3,000–4,000 hours and being built up to a capacity of 10,000 volts and 30 amperes.

Batteries do not appear to be much used except in some of the larger towns; a large one of 8,000 ampere-hour capacity at 250 volts is installed in the sub-station at San Francisco, but in general the amount of attention and maintenance which they require appears to militate against their use more than it would in England. The chief use of the one at San Francisco appears to be to act as a reserve and keep up supply in the event of a breakdown of the transmission line.

It is very rarely that separate generating plants are provided for traction and lighting service. One company usually operates the whole, from one system, and this, combined with the large use of power for heating, power and elevator service, probably tends to the realisation of a better load factor than obtains on the average English station.

Sub-stations for Changing Frequency.

When low-frequency current has to be distributed for lighting purpose it is the usual practice to instal frequency-changing plant; this consists of motor-generator sets, many of them built on vertical shafts. The type of motor may be either synchronous or induction, and the generator is of the ordinary revolving field pattern. These frequency changers are, of course, only used when the frequency of generation is 25 or 30 cycles per second. It is remarkable that very little lighting has been attempted at the lower frequencies. With

incandescent lamps, either of the carbon or Nernst pattern, the flicker when the lamps are supplied with current at 25 ∿ is imperceptible, and even with metal filament lamps this effect is hardly noticeable. The only lamps with which such a low frequency becomes a matter of importance are arcs; but as, on an alternating current, all arc lamps are notably inefficient as compared with direct-current ones, it hardly seems worth while changing frequency in order to make alternating lamps effective. In some places sub-stations containing machinery of 35,000–40,000 k.w. have been installed to change the frequency of supply from 30 to 60, and to an impartial observer it would seem a far better plan to have spent the money so invested in improving the distributing system.

In conclusion, we wish to express our indebtedness to the many engineers who were good enough to give us facilities for examining the many stations that have been visited, in particular we would mention Professor Herdt, of the McGill University, and engineer to the Winnipeg scheme, and Mr. F. V. T. Lee, the engineer to the Pacific Gas and Electric Company, of San Francisco.

Discussion.

Mr. T. L. Miller: The remarks I have to make deal more particularly with the second portion of the paper—viz., the Modern Practice of Hydraulic Plants. Under the head of "Economic limits of Transmission" the authors state that "the capital charges in connection with hydro-electric schemes are by far the most important in determining the cost of energy," and later on they give some figures of hydro-electric stations and transmission lines. It is, of course, difficult, if not impossible, to give average figures, as the conditions vary greatly. In some cases the local conditions are so favourable that water-power can be developed at an almost nominal cost, while in other cases unforeseen circumstances have so enhanced the cost of development as to make the cost of water-power greater than that of steam-power. According to Professor Janet, the cost of water-power development in France varies from £4·28 to £30 per horse-power, depending on the head to be dealt with, the lowest expenditure being upon a fall of 140 metres in Haute-Savoie, the horse-power being calculated at the turbine shaft. Mr. Miller.

For the two stations of the Societa Idroelettrica Ligure, Milan, the first of which will generate 28,000 H.P. with a fall of 1,150 ft., and the second 17,500 H.P. with a fall of 625 ft., the capital cost, including transmission lines, step-down transformers, and secondary distribution, is estimated at slightly over £14 per horse-power developed. For the scheme for developing the Cameron Rapids, Ontario, Canada, the plant capacity being 16,350 H.P., the cost per horse-power installed, including 75 miles transmission, is given as £17 12s., and the generating and transmission expenses per horse-power-year, including interest (4 per cent.), maintenance, and depreciation, as £1 13s. 8d. per horse-power-year. Professor S. P. Thompson

Mr. Miller. published some figures some little time ago regarding the cost of water-power used at Notodden for the Birkeland and Eyde nitrogen-fixation process, from which it would appear that the present total costs per unit amount only to 0·025d., and that at the new power station at Svälgfos they will be but 0·015d. per unit, equivalent to 13s. 7d. and 8s. 3d. per horse-power-year respectively. It is not clear, however, whether their figures include interest and replacement fund charges. As an example of a small water-power plant, I would give the case of the Westerwick power station, South-east Sweden, where the plant capacity is about 1,300 H.P., and the power is transmitted 9 miles, the line voltage being 10,000 single-phase. The cost of the hydraulic construction amounted to £5·6 per kilowatt installed. The cost for works (including hydraulic development) was £9·05 per kilowatt, and for line £2·6 per kilowatt, making a total cost for works and line of £11·65 per kilowatt.

Dealing now with the modern practice, I should like to ask a question with regard to the American practice in making the joints in the pipes on their hydraulic power schemes. Over here we have had one or two examples, perhaps the best known being that of the Power Company of Snowdon. When this company first put down the plant they used ordinary socket and spigot pipes, but it was found that the pressure was too great and that they were unable to keep the joints tight, and they were obliged to put in glands fixed with bolts in order to keep the packing in. This is practically the same as the muff joint, in which there is a special gland keeping the packing in position. These pipes are extremely handy in that they allow certain deviations in line, and also allow for expansion. When the pressure is not great of course ordinary socket and spigot pipes may be used. We are carrying out a scheme in India where flanged pipes with corrugated metal rings are used for jointing the main line, expansion joints being placed at intervals to allow for temperature variations. The difficulty is to put in the closing length, for as long as the water is going through the pipe there is little trouble from expansion, but until the water is admitted to the pipe, the difference in expansion between day and night is often considerable and causes a great amount of trouble.

Another, and one of the most important points, as the authors have already stated, in the design and working of hydraulic plants is the question of governing. Of course, where you can use the deflected nozzle it is probably the safest method, but there are cases when, owing to the scarcity of water, different arrangements have to be used, so as to economise the water supply. In some governors arrangements are made so that when the governor acts to reduce the flow of water, a byepass is opened which allows the surplus of water to flow into the tail race, the byepass being slowly closed so as to relieve the pipes from shock. In many instances I believe this arrangement is relied upon absolutely, but I think, in addition, relief valves should be fitted on the receiver on the main pipe-line, as in the event of the governor sticking there is danger of serious trouble with the pipe-line. Another point in

Mr. Miller.

the construction of water-power plant is to construct the generator so that in the event of the governor failing and the speed running up, the generator will be able to withstand the stresses due to centrifugal force at the high velocities attained. The members will no doubt remember reading some months ago of the total shut down of a power station in the States due to this cause. I was very much interested in the surge-pipe in the diagram shown on the screen, but it appeared to me that that surge-pipe did not protect the lower length of pipe; it might have protected the tunnel but not the pipe-line. Of course, the adoption of what one might call an air buffer is right enough so long as the air supply is maintained, but unless fresh air is constantly supplied it passes away with the water and the buffer action disappears.

The question of the poles has been raised by the author, and he points out that America has been referred to as the home of wooden poles. The latest development to-day is reinforced concrete poles; these, I believe, will be used very largely, being lighter than iron, and not subject to the same depreciation as the wooden or iron poles. Where wooden poles are attacked by insects reinforced concrete helps one considerably. I would remark that we recently obtained tenders for steel poles and towers for various spans in connection with our Indian scheme, the poles being constructed to carry three No. 6 B. and S. wires and two No. 12 S.W.G. telephone wires, the spans being 300 ft., 400 ft., and 900 ft. respectively. For the 300-ft. span the pole was made up of three sections: 10½ in. outside diameter by ⅜ in. thick for the bottom, and 8½ in. outside diameter by ⅜ in. thick for the intermediate section, and 7½ in. outside diameter by No. 2 S.W.G. for the top section, the price with crossarms being £14 15s. For the 400-ft. span the tower was made up of 3 poles 6½ in. outside diameter by $\frac{3}{16}$ in. thick lower section, 5½ in. outside diameter by $\frac{3}{16}$ in. thick intermediate section, and 4½ in. diameter by $\frac{3}{16}$ in. thick for the top section, the poles being arranged triangular in plan and braced and constructed so as to form a rigid structure. The cost of these was £47 10s. each. For the 900-ft. span the tower was made up of 4 poles arranged to form a square on plan, each pole being 7½ in. outside diameter by ¼ in. thick in the lower section, 6½ in. outside diameter by $\frac{3}{16}$ in. thick in the next section, 5½ in. outside diameter by $\frac{3}{16}$ in. in the upper middle section, and 4½ in. outside diameter by $\frac{3}{16}$ in. thick in the top section, the poles as in the previous instance being well stayed and strutted, the cost being £109 per pole. It will be noticed here that while the span is increased three times, the cost is increased eight times. It should be mentioned that these prices include galvanising and delivery C.I.F. Calcutta. For poles and towers for similar spans made to American designs the corresponding prices were £68, £117, and £222. These figures are, I think, extremely interesting from the point of view of the relative prices of pole towers designed for similar conditions by American and British manufacturers, the British design being much more substantial and very much cheaper than the corresponding American designs. The factor of safety in all cases is taken

Mr. Miller. as 5, and rigid tests were specified to be carried out on all classes of poles before delivery.

In his recently published book on "Heavy Electrical Engineering," Mr. Hobart gives the figures relating to the cost of poles and towers, from which the following has been extracted :—

COST OF POLES AND TOWERS.

Type of Construction.	Average Cost per Pole or Tower.	Average Span.	Cost per Mile.
	£.	Feet.	£.
Wooden pole ...	3	110	96
Steel pole	8	230	184
Steel and tower ...	25	460	275

The price for the 400-ft. span poles is, however, considerably lower than the tenders we have actually obtained, and I can only assume that they are working with a very much lower factor of safety; however, the relative costs will probably not be far out, and the figures are interesting, as showing the relation between span and cost of towers.

Dealing now with the question of the lines, I find that the factor or safety used over in the States is in many instances very much below what would be required in this country. For example, the maximum permissible stress occasionally allowed in America is as high as 2,840 lbs. per square inch, this occurring when lowest temperature (taken as —25° C.) and maximum wind pressure (about 30 lbs. per square foot). This is slightly lower than the elastic limit, and is roughly about half the breaking strength of hard-drawn copper. In an extremely interesting paper read by Mr. D. R. Scholes before the American Institution of Electrical Engineers on "Transmission Line Towers," curves are given for a 3-phase alternating-current system with conductors 0·3145 sq. in. area and 0·73 in. outside diameter, and spans of from 100 ft. to 1,000 ft., from which Mr. Scholes showed that the most economical span was from 400 to 450 ft., and that the cost per 1,000 ft. of line, including tower foundations and insulators, but excluding line, amounted to about £52. Of course, the figures are for lines carried out in accordance with American practice, and would hardly be comparable with the requirements in this country, where the work would require to be carried out under Board of Trade conditions, which are more onerous.

I have been particularly struck by the diagrams shown by the authors, some of them being of extreme interest as showing what is permitted where engineers are allowed to go unchecked by the restraining influence of a Government department such as the British

Board of Trade. Indeed, looking at some of the illustrations, one cannot help feeling that there must be a special Providence looking after the safety of the work of American engineers in the running, maintenance, and upkeep of some of the constructions shown. Mr. Miller.

Mr. J. S. PECK: The paper is of great interest as showing the remarkable progress in long-distance transmission in the last few years. Five years ago there were a number of 30,000- and 40,000-volt transmission systems, and three or four which were operating at from 50,000 to 60,000 volts. Now the authors refer to 60,000 volts as the standard pressure for long transmissions, and to 100,000 and 110,000 volts as high pressures. While it is true that the principal electrical developments have been about Niagara Falls and on the Pacific Coast, very extensive developments have been going on in the Southern States, where there are some very large high-voltage transmission systems. Mr. Peck.

I think every one will agree with the authors in their statement that 60 periods is not the most desirable frequency for long-distance transmission, but this frequency was adopted as standard almost before long-distance transmissions were thought of, and it would be a very costly undertaking to alter this frequency now. Regarding electrolytic arresters, I note that the authors state it is customary to connect the arresters to the line every other day. This is done to make sure that the film on the aluminium plates is kept up to its full strength, for if the film is allowed to deteriorate, the arresters may take an enormous current in the event of a lightning discharge.

I do not see why properly transposing the telephone line should not eliminate the effects due to electromagnetic induction. Electrostatic effects, however, cannot be eliminated in this manner. The relative advantages of the star and delta systems of connection for transformers have been the subject of much discussion. The great advantage claimed for the delta system is that the line may be run with one wire grounded, which is not possible on the star system, where the neutral is earthed. There is very good reason for using independently driven exciters, particularly on water-power plants, where good speed regulation of the water-wheels is difficult to obtain. If the exciter is direct-connected, then any variation in speed on the main generator will vary the exciter voltage, so that the voltage on the generator will be varied to a much greater extent than the variation in speed, whereas, if the exciter is independently driven at a constant speed, the voltage variation on the main generator will only be that due to its own speed variation. It has been clearly demonstrated that in order to protect thoroughly the windings of high-voltage apparatus from static discharges a choke coil of high self-induction is required, and choke coils are designed with special reference to the apparatus which they are to protect.

Mr. S. L. PEARCE: The question of the capital costs of these water-power schemes is one that should not be lost sight of. On page 437 the authors have given us a few figures relating to this point. In connection Mr. Pearce.

Mr. Pearce. with the stations at Niagara, the cost is given at from £20 to £30 per kilowatt, including the transmission line. I should like to know the approximate length of that transmission line. In making a comparison between the capital costs of a water-power station such as those at Niagara and a modern steam-turbine station, allowing £10 per kilowatt for distribution, it appears the steam station would still have a substantial advantage. One is rather strengthened in this belief by the views expressed some four years ago when our international friends came here, and appeared to be immensely struck by our somewhat low capital expenditure on large turbine stations. When one remembers what an important bearing the question of capital costs has on supply rates, one is further strengthened in the belief that these water-power stations have not after all such a very great advantage in comparison with steam-turbine plants. As far as I know, the average rate for power supplies in the States is certainly in excess of that at which electrical energy can be procured in England. Dr. Marchant touched very briefly on the possibility of applying a large overhead transmission system to this country, particularly to this district, and previous speakers have drawn attention to the fact that there is no Board of Trade in America. Admittedly, the question of wayleaves plays a very important part, and no doubt there are engineers in this room who have at some time considered the question of an overhead transmission line as an addition or extension to their existing underground system, and know the practical difficulties. In the case of Manchester, some two or three years ago we considered the advisability of dealing with the supply to some of our outlying districts, such as Denton, Droylsden, and Audenshaw, by means of an overhead line, and on going into the matter we found that we could only expect to save at most 20 per cent. as compared with an underground system. Moreover, restrictions were laid down that certain roads would not be allowed to be crossed overhead, and by the time these difficulties had been met, there was practically little saving to be effected. Even in America I believe that some engineers, for the sake of perfect reliability and to avoid risk of failure, would hesitate to tack an overhead line on to a system which has already 75 to 80 per cent. underground to commence with. In considering the older portion of the underground system, one has to take into account whether protective devices on the overhead line are a sufficient guarantee to secure immunity from trouble through excess pressure on the underground work. I believe there are quite a number of examples where engineers prefer to keep to an underground system throughout, and would pay more to have an absolutely reliable system. I am not arguing against overhead lines *per se*, but only questioning the advisability of tacking such lines on to an existing underground system where the maximum saving might not be more than 20 per cent.

On page 432 the authors refer to the great aversion that exists to using 25 periods for lighting. That is a little surprising, because I believe this has been done, and is done successfully in this country at the present time. I believe the proposals under the London County

Council Power Bill of 1907 contemplated 25 periods, and that included lighting and power. The question of delta-delta connections for transformers is also interesting. There is no doubt that the advantages lie with delta connections, at any rate for power work. The reasons are very clearly set forth in this paper, and have been dealt with at considerable length in previous papers, the main point being one of reliability of supply. If the consumer wants lighting as well, there is an arrangment (which I think is due to Mr. Peck), viz., the introduction of interconnected star-balancing coils for giving the neutral-point for lighting purposes. In connection with the low-tension distribution, it seems to me that these coils can be used with some advantage, especially as regards saving in capital expenditure, to supply undertakings, because instead of distributing four wires one can drop out the fourth wire altogether and simply use these balancing coils on consumers' premises where the neutral-point is required. Mr. Pearce.

Professor A. SCHWARTZ : There are several points on which I should like to ask questions, but I will confine myself to the line construction: First, on page 429, where a formula is given for the electric strength of air, I presume that this formula is based on experiments made on cylinders. In this connection it is interesting to note that Professor Kowalski, of Geneva, has recently experimented with spheres of 30 cms. diameter, and found that the electric strength of air is as low as 28 kilovolts per centimetre. The authors state that the presence of water vapour in the air affects the electric stress allowable. At the School of Technology we made some experiments in the high-tension laboratory a little while back, in which we discharged steam through a pipe on to a wire carrying a pressure of 100,000 volts, and we were surprised to find that the steam was deflected very strongly away from the wire. I should like to ask the authors whether possibly the immediate neighbourhood of the wire is not the driest point in the district at the time. Professor Schwartz.

On page 443, with regard to insulator construction, porcelain has very different strengths in tension and compression. Some time ago we made experiments on some specimens which were kindly furnished by Messrs. Taylor and Tunnicliffe, on test-pieces in vitreous high-tension porcelain made up with expanded ends like cement briquettes. We found that in tension their strength ranged from 3,136 lbs. per square inch for a rectangular test-piece, with a section of 0·2 sq. in., down to about 2,000 lbs. per square inch for a rectangular test-piece with a cross-sectional area of about 0·6 sq. in. The reason that the tensile strength diminishes with the larger size test-pieces appears to be due to the fact that in firing the porcelain the action of the heat has not been so great at the centre of the cylinder as it has on the outside, and consequently with the large test-pieces the porcelain is not quite so vitreous in the interior of the mass as is the case with the smaller test-pieces. I find the same effect with cylinders tested in compression: with cylinders 2 in. long and 2 in. in diameter, the breaking-load per square inch was about 10,000 lbs.; for 1 in. diameter test-pieces it rose to 40,000 lbs.,

Professor Schwartz.

and for $\frac{7}{16}$ in. diameter it rose to 52,600 lbs. Considering that such a great difference exists between the strength of porcelain in tension and in compression, we ought, I think, to design our insulators so that the porcelain is in compression at the point of support.

If you turn to the illustrations, you will find that Fig. 17 gives us the Locke pattern suspension insulator, in which the porcelain is in tension, whereas Fig. 18 gives us the General Electric suspension insulator in which the porcelain is in compression. In the latter type of insulator the support is formed by two wire cables interlinked with one another, with the porcelain between them in compression. Porcelain is comparatively trustworthy when in compression, but when in tension it is not trustworthy unless very special precautions are taken to ensure that the bearing surface of the supports is not localised. The specimens which were made for us were, as I have said, shaped like a cement briquette, but in spite of the ends being lapped with paper to secure even bedding, a large number of them broke at the grips, and they broke with a characteristic bulbous fracture, the apex of the bulb being at a point where the pressure had been localised. Will the authors give us some more information about the cementing materials which are used for these insulators? As far as I am aware, glycerine and litharge, sulphur, Portland cement, and white metal have all been used for cementing materials, and it seems that the best form of cement to use is one which, like white metal, is unaffected by the weather conditions. Sulphur is a very objectionable material as sulphuric acid is produced.

With regard to the long spans, the great advantage seems to be that there are fewer wayleaves to negotiate, and fewer insulators to provide and maintain. I should be glad of some information as to the cost of upkeep for inspection and cleaning of the insulators, and whether the suspension type of insulator is more difficult to clean than the pin type. The authors have not given us any information as to the factor of safety for the line construction; they tell us it is not infrequent for lines to be shut down in winter-time, and I should like to know whether this is due to the ice troubles which have been mentioned by Mr. Peck, or whether it is due to the breakage of the overhead line from the accumulations of ice and snow. Overhead wires in this country suffer from the accumulations of ice and snow, and we sometimes find in this city that we are isolated from the rest of the country because of the telephone wires being down; it is not necessary that this should be so, and I would instance the case of the Kander power house on the Burgdorf-Thun Railway, the overhead lines from which I have seen in satisfactory operation with the thermometer 20° below zero Fahrenheit, and a fall of 3 or 4 ft. of snow.

Mr. Walker.

Mr. M. WALKER: I should like to raise two questions: (1) Do the authors believe, from what they have seen in America, that it is possible to construct a transmission line which would be practically free from breakdown? (2) Does the good operation of the American lines in damp weather go to show that we could work at 50,000 or

100,000 volts in this country with its humid climate? If these questions could be answered in the affirmative then we might perhaps have long-distance transmission in this country from the coal-fields to large towns, for on a sufficiently large scale it appears more efficient to transmit electricity than coal. Mr. Walker.

Consider a line in triplicate consisting of 9 aluminium wires each 1 in. in diameter as a means of transmitting 100,000 k.w. to London from coal-fields 100 miles away. The wires being of large radius might work well at 100,000 volts, but we will take 75,000 volts. The drop would be 5,000 volts or 7 per cent. The weight of the aluminium would be less than 2,000 tons, and the cost at present prices less than £140,000. If we allow a capital expenditure of £3,000 per mile for poles and wayleaves, etc., the total cost of the line would be £440,000, or, say, £44,000 per annum. Now, consider the saving in cost of coal. At the pit's mouth it is possible to generate electricity at a cost for coal of only 0·1d. per unit if the demand is very great and the load factor as high as 33 per cent. Under the same conditions in London it is not likely that the coal will ever cost less than 0·2d., that is to say, the efficiency of transmission of coal is not greater than 50 per cent. Now, 100,000 k.w. with a load factor of 33 per cent. means $2 \cdot 8 \times 10^8$ units per annum, and with a saving of 0·1d. per unit we have a total saving of £120,000 per annum without counting the other obvious advantages. But of course this is not possible unless we can give continuity of supply and can work with safety in this country at such high voltage.

Mr. C. H. K. CHAMEN: In transmission practice my experience has only been with 10,000 volts, and the requirements of this country are not likely to approach the conditions mentioned in the paper. One hundred and sixty miles of transmission line and voltages up to 160,000 will never be wanted in this country, as generating centres will be closer together, and not having the water-power that is at the disposal of the countries mentioned in the paper we shall therefore always look to coal for our source of supply. Upon the subject of overhead lines, it has now become an established fact that overhead lines at 10,000 or 20,000 volts worked very satisfactorily, and I think that no mains-men who have worked both overhead and underground systems will disagree with me when I say that it is not the overhead system which gives them the greatest anxiety or that costs them the most money in maintenance. It is obvious that an overhead line is very easily repaired if trouble occurs to it. Mr. Chamen.

With regard to the question of lightning troubles, while noticing that the authors say that there is less likelihood of these troubles on high-voltage lines than on low-voltage lines because of the high insulation, they still speak as though they considered that protection against lightning was necessary even on these high-voltage lines. I have known 10,000-volt lines, without any protection against lightning or any line protection whatever, except spark-gap and carbon-rod devices at the power station, to live through the worst thunderstorms which I have experienced in this country, which did damage

Mr. Chamen.

in the close vicinity of the lines under my charge at that time, but none whatever to the lines themselves. I feel assured that in adding lightning arresters to a line one is only asking for trouble, as having by this means invited the lightning to come into the line on its path to earth we shall probably find that there is not sufficient path for the lightning through the devices which have brought it into the system. As regards the question of an earth wire being run over the top of the high-tension lines, this is, of course, the very reverse of a lightning arrester, but even in the use of this it would appear to me that trouble is more or less asked for, as lightning will assuredly use this line on its path to earth, and even if it finds the path of sufficient capacity it may still induce a high potential to earth on the line itself in so doing. At any rate, I have to say from my own small experience, and from what I have heard from other mains-men working on 10,000-volt lines in this country, that I am of opinion that lightning arresters are not only of no use, but a distinct danger to the line.

Dr. Rosenberg.

Dr. E. Rosenberg: The authors mention the use of asynchronous generators, but the advantages of this type of generator are very often over-estimated. It is generally assumed that the induction generator can be thrown straight on to the line without synchronising. This may be right for very small machines, but with machines of any appreciable output great precautions must be taken in order to avoid the dangerous rushes of current which otherwise would occur. This is already true of induction generators of a few hundred horse-power. Readers who will refer to Mr. Rider's paper on the London County Council tramway system will find that in case of 500-k.w. motor-generators the machines are brought up to synchronous speed from the direct-current side, and a stroboscopic device is used to ascertain the exact synchronous speed before switching the induction motor on to the line. Even then a rush of current occurs, just the same as when connecting a transformer suddenly to full voltage, and in order to reduce too heavy rushes choking coils are temporarily inserted. I would ask the authors whether, with the exception of the small asynchronous exciter motor generator turbine sets mentioned under (*f*), they found examples of induction generators in the stations visited by them, and what size they were.

Mr. Worrall.

Mr. G. W. Worrall: I recently had the opportunity of visiting some of the hydro-electic power stations on the Continent, and it has given me great pleasure to hear what is being done in the United States. During my visit I was very much impressed by the design of the switchgear and the precautions taken to ensure continuity between the generators and the line. The control of the oil switches was in all cases electrical, and generally operated from some form of desk switchboard from which the attendant could see the machine he was synchronising. I saw the operation of synchronising carried out on several occasions, and do not think that the pneumatic control could be any more certain or quick in action. The latter has, however, the advantage of perfect insulation, which perhaps is necessary when the

voltage exceeds 100,000. I am surprised to hear that the water-jet arrester is not employed in the U.S.A., for in almost every station I visited it was in continual use. The power absorbed by one jet is only about 5 k.w., which is quite a small item in the total power of a large station, and is a small price to pay for the safety it ensures. Mr. Worrall.

The danger of the water turbines racing when the load is variable has been overcome in several cases by the use of artificial liquid loads, which are automatically regulated to maintain the total load constant. The most interesting case of this kind is at the Simplon Tunnel Power Station, where the power must always be available, while the load varies from zero to full as the trains pass through the tunnel. Two examples of the Thury system of direct-current transmission were included in my visits, and in both cases an additional generator was put in circuit in my presence. This operation consists merely of bringing the generator up to such a speed that it generates the full-load current on short circuit, and then opening the short-circuiting switch; the regulation of the other generators is quite automatic. The simplicity of this operation and the absence of all complicated and costly switch-gear are greatly in favour of the adoption of the Thury system, and when it is remembered that according to modern ideas the continuity of supply is mainly dependent on the switch-room, the Thury series system should be at least as reliable as alternating current with parallel operation.

Mr. A. P. M. FLEMING: With reference to the choice between star and delta systems, a point has been raised in the discussion in regard to the use of an inter-connected star balancer on delta lighting systems, where it is desirable to obtain a neutral-point for lighting voltages. I would point out a further use for this apparatus, and its influence on the choice of star or delta connections for step-down transformers supplying mixed power and lighting loads. A 3-phase transformer combination is cheapest and most efficient when connected in star on both high- and low-tension sides, but for balanced lighting on the low tension between outers and neutral it is necessary to bring the neutral back from the lighting distribution to the star-point of the transformer, and also to connect the neutral-point of the high-tension side to that at the generator end, in order to avoid unbalanced ampere-turns on the different phases of the transformer and consequent unbalancing of voltage. When the inter-connected star balancer is used, the neutral connection on the high-tension side is unnecessary, and it can also be dispensed with on the low-tension side between the main transformer and the balancer. A similar economy as regards cost and efficiency of main transformer is obtained when the latter is connected in star on the high-tension and delta on the low-tension side, and in this case the balancer provides the neutral-point for the lighting voltage. Mr. Fleming.

In regard to line construction, the voltages heretofore employed in this country have not been high enough to demand serious con-

Mr. Fleming.

sideration of the relative merits of the pin-supported and suspension types of insulator. The authors state that the prevailing practice in America is to use the pin-supported insulator for voltages up to about 60,000, and I should like to have their opinion as to whether the suspension type could not be economically employed for much lower voltages. From an electrical point of view the maximum voltage for which the pin type of insulator is suitable is limited by the intensity of stress in the comparatively small thickness of porcelain between line and ground, *i.e.*, pin-head, since for voltages of the order of 60,000 a metal pin is necessary for the reasons given in the paper. The thickness of material above the pin-head can be made ample for low voltages, but cannot be safely increased in proportion to the voltage, as the stability of the support is weakened, and difficulties are met with in the manufacture of the porcelain. This steep potential gradient between line and pin-head, in addition to stressing the material at its thinnest section, tends to produce a discharge over the outer surface of the insulator, which may cause a flashover from line to pin, and also tends to produce heating around the pin-head unless the fit in the porcelain is very good. The contour of the petticoats of the insulator can be so designed as to reduce to a minimum the tendency to flash over, but the insulator becomes a complicated affair, and requires to be built up in several parts cemented together, and a material having a very doubtful insulation value at high voltages at the point where the stress is greatest is introduced. In the case of the suspension type of insulator the entire stress between line and ground is more or less equally divided over a number of separate units, ample surface insulation can be provided without undue increase in weight or complexity of design, and if one unit is mechanically damaged the insulation value of the entire insulator is not destroyed, also a greater factor of safety can be obtained without much increase in cost. I should be glad if the authors could give some comparison in cost of insulators and mounting for both types for, say, a 60,000-volt line, and express an opinion as to the lowest voltage at which the suspension type may be economically used.

Mr. Mallinson.

Mr. A. B. MALLINSON: One of the weakest parts of an overhead transmission line as at present installed in this country is in the neighbourhood of the guard nets required where crossing public roads, etc. I should gather from the author's paper that in the general American practice they are little, if ever, used. That seems to me a step in the right direction, in that it simplifies the system. If the line is well designed and carefully erected, there is little or no reason why breakages should occur; but the addition of a number of guard nets must sooner or later cause interruptions of supply from short-circuits caused by broken guard nets. The precautions taken to guard against water hammer, already alluded to by Mr. Miller, are of great interest. In pumping by turbine high-lift pumps to considerable heads, say, 500 to 1,000 ft., very much the same conditions are found, and I have seen some disastrous results occur due to the failure of power to the motor

when pumping. It is now common practice to fit relief valves at the bottom of the pipe-line to safeguard this, but in some recent instances I have seen relief valves fitted not only at the bottom, but along the pipe-line, especially if there are any bends in it. Mr. Mallinson.

Mr. G. HARLOW: In high-tension transmission schemes the high-tension switchgear forms a considerable item in the cost of the scheme, both with regard to the gear itself and the additional room required in the generating stations and sub-stations for its accommodation. Recently in a great many schemes it has been proposed to do away altogether with high-tension switchgear, and to carry out all switching on the low-tension side of the transformers. In these days, when transformers can be built at a comparatively small increase in cost to withstand any desirable insulation tests, it would seem that the above operating conditions have a great chance of being successfully introduced, and I note that within the last two years such a scheme has been put into operation at the Grand Rapids, Michigan. This scheme is fully described in the *Western Electrician*, of October 3, 1908, and operates at 110,000 volts, 30 periods, has a capacity of 11,250 kilo-volt-amperes, and is 50 miles in length. At the time of the above article the system had been in service only ten weeks, and I should like to ask Professor Marchant and Mr. Watson if they had an opportunity of inspecting this installation, and as to its reliability during the past fifteen months. I understand the transmission line is not equipped in any way with protective gear, either in the form of lightning arresters or a ground wire, and is reported to have withstood without the least damage extremely severe atmospheric conditions. Mr. Harlow.

With regard to Professor Marchant's statement that the advantage of the delta connection is not practically important, it is found that 60,000 volts working with the insulators installed are rarely large enough to withstand the full-line pressure, and if one of the phases break down the line is put out of service for the time being. It would seem that this weakness of the line insulators is radically wrong, in that it does away with the great advantage claimed for systems operating with unearthed neutrals.

Mr. S. J. WATSON: I note that the system devised by Thury of transmitting by means of high-tension continuous current with constant current through the line and a variable pressure does not appear to have been tried in America. Where a number of comparatively small power stations are run in parallel on long transmission lines better results would have been obtained with such a system, and as the cost of insulating the overhead lines depends on the maximum voltage it is obvious that the cost of the line would be considerably less for direct current than for alternating current. At the same time it is of interest to find that the Americans appreciate one of the features of the Thury system, for the present practice appears to be to construct a line for a very high pressure, and to commence supplying at any convenient lower pressure, then as the connections to the line increase the pressure is also increased from time to time up to the limit—that is Mr. Watson.

Mr. Watson. to say, they endeavour as far as possible to work with a constant current and constant transmission losses.

In connection with the remarks *re* long-distance transmission from collieries, I do not think there are likely to be many schemes of that kind in this country, principally because the total power requirements of industrial centres is so large. In the manufacturing towns of Lancashire, Yorkshire, and the north-east coast the power consumption is from ½ to 1 H.P. per inhabitant. Manchester, with a population of 700,000, has probably a possible demand of upwards of half a million horse-power, and I do not think it would pay to generate that amount, say, in the Wigan district and transmit to this city. The capital cost would be so great on the transmission lines that I feel sure it would be cheaper to bring the fuel and have the power station nearer the centre of the population. I wish the authors had given us some idea in regard to the cost of coal on the Pacific Slope, from which district many of their examples are drawn. We should then have been in a better position to make a comparison between a steam station, with its comparatively small capital cost, and the water-power schemes, where so much has to be spent in constructing reservoirs and flumes for the storage and conveyance of the water. The authors mention the cost of land as £60 per mile of line. Does this include the cost of land for the power station, or is it only the cost of land required for the poles and purchased outright as distinct from an annual rental for the land occupied by the poles?

I find that the transmission capacity of some of the very high-voltage lines mentioned appears to be from 10,000 k.w. to 20,000 k.w. This seems a very large load to depend on one set of lines. The Board of Trade in this country deprecate anything over 1,000 k.w. for underground work. After seeing the photographs showing the arrangement of overhead wires, one is hardly surprised to hear that entire districts are occasionally shut down. Such a condition of affairs would not be tolerated in this country where continuity in the supply is considered of the first importance. The interconnecting of power stations is of interest; it appears that American engineers more fully appreciate the advantages of doing so than we do, as instances are given in the paper of interconnecting such small plants as 100 k.w.

Mr. Lee. Mr. F. V. T. Lee (*communicated*): The terms "induction" and "inductor" generator have been used more or less indiscriminately in this country and elsewhere without proper distinction. I assume that the authors refer not to what we call the "inductor" machine in which the field structure revolves within a stationary magnetising coil or field winding, nor to what is known as the "no-moving-wire" machine, a number of which we have on the system, but that the apparatus they refer to is the induction motor which has the characteristic of becoming an induction generator when provided with a magnetising current and driven above synchronous speed, and it is to this latter type of machine that I refer. We have quite a large number of these machines on our system, and use them, in fact, in all our large power houses—viz.,

de Sabla, Centerville, Colgate, Deer Creek, and Electra. You will appreciate that these are not used as induction generators for their value as energy producers, but merely for the purpose of taking advantage of their characteristics in governing the exciter water-wheels. Mr. Lee.

The history of the introduction of these units has never been definitely published. About 1898 or 1899 (the exact date I am not able to give at the present time) in the installation of hydro-electric plants a great deal of difficulty was experienced in obtaining a satisfactory water-wheel governor for the purpose of obtaining regulation to admit of parallel operation. A great many governors were tried, and eventually the Lombard governor and governors of similar character were adopted for the generators. However, they were at that time (the plants being small) considered too expensive for the exciter sets which were then, as now, almost entirely water-wheel driven, being the successors to the belted exciter with its inherent difficulties: that is, when the generator tended to slow down owing to a sudden load coming on the belted exciter slowed down also, with the result that at the time an increased field was needed, the field was actually weakened. This had led to the installation of water-wheel driven exciters. With the water-wheel driven exciter, however, the cost of a good governor seemed prohibitive, and the ordinary induction motor-driven exciter, through the poor speed regulation of the induction motors then commercially obtainable, was almost if not quite as bad as the belted unit, about the only difference being that there was no exciter belt to break. Another difficulty that was experienced, particularly in the high head plants, was that owing to the smallness of the nozzle on the exciter wheel it was very readily choked up by twigs and other small articles, with the result that the plants not infrequently shut down from that cause. In the East at Niagara the difficulty of regulation was lessened by placing an artificial load in the form of a resistance in the shunt with the generator fields. The exciter wheel was then run at constant load, which was divided between the resistance and the generator fields as conditions required. A constant load, however, was kept on the water-wheel at all times. Another plan considered out here by the late Mr. Theodore E. Theberath, member of the American Institution of Electrical Engineers, was the substitution of a battery for a resistance so that the exciter and its wheel was continuously operated at full load, and in case of exciter water-wheel trouble the generators were carried on the battery. The installation of batteries, however, was considered too expensive in small plants, and their subsequent maintenance and repair called for considerable labour and special materials, electrolyte, etc., which were not always available at the small power plants in the mountains. Theberath and myself, therefore, in order to do away with the induction motor, developed a scheme using a synchronous motor, water-wheel, and exciter coupled together on the one shaft, and operating the other water-wheel at full load at all times. The difficulty with this, however,

Mr. Lee. was due to the fact that if for any reason there was trouble with the water-wheel the synchronous motor fell out of step, and it would be difficult to start it again. A special design of synchronous motor was then got up that would have some of the self-starting characteristics of the induction motor, but the set was never built, since about this time Steinmetz's paper on the induction generator was published, and Theberath immediately recognised that this machine had the characteristics of that we were looking for. A set was installed, and the results obtained were so good that they have been used ever since on this system, and in fact the Theberath exciter set will be found in use on most systems in the West.

Mr. L. M. Hancock, associated with this company about the same time, also did some work along the same lines as Mr. Theberath. As far as I know, these sets have not been used very much in the East or in Europe, but I think anybody who will consider the matter will appreciate that they are ideal and give a guarantee of operation that cannot be obtained otherwise. I have extended this idea in connection with turbine stations, and I propose to put down in our steam turbine station when it is enlarged a small steam turbine direct coupled to an exciter with an induction motor on the same shaft. This will then operate exactly as do the water-wheel sets, and will eliminate the governor troubles that have been apparent with steam turbines in small sizes due to the smallness and delicacy of the parts involved.

Professor Marchant and Mr. Watson. Professor E. W. Marchant and Mr. E. A. Watson (*in reply*): The figures given by Mr. Miller for capital cost are much lower than for most American stations. Professor Janet's figure of £4·28 per horse-power can hardly refer to the total cost of a hydro-electric station, as it would not cover the cost of the electrical machinery alone, except in very large sets. The cost of £2·6 per kilowatt for the line at the Westerwick power station is remarkably low; it corresponds with a total expenditure of £280 per mile of line including, we presume, poles, insulators, and copper.

The method of jointing pipes was not observed at all the stations visited, but the spigot and socket joint was the most common. Very little trouble appeared to have occurred from leaking pipes. At Island Bar the pipe is protected by relief valves, and the surge-pipe serves to prevent inertia effects due to the large mass of moving water in the tunnel. Both forms of protection are used, as stated in the paper. The air compressor for protecting the pipe-line was not at all common; with proper precautions for maintaining air in the cylinder it would appear to be an excellent protective device. No reinforced concrete poles were seen; the prices given by Mr. Miller for the 900-ft. span tower are much higher than those given for these towers by American engineers. Possibly the high price is due to the massive construction adopted. All steel towers that we saw were built up from channel and angle iron of standard section well braced together. Hobart's figure for wooden poles is £144 per mile of line, and he gives as the price of steel towers for a 500-ft. span £12 to £40 per tower, a figure much

Professor Marchant and Mr. Watson.

more in accordance with those given to us by American engineers than the £117 per tower for a 400-ft. span given by Mr. Miller.

Mr. Peck has mentioned the recent developments in the Southern States. These are not referred to in the paper, as those States were not visited. There is a very large and most interesting distribution system at Los Angeles which differs from nearly all the others on the Pacific Coast in that a frequency of 50 cycles is employed. The pneumatic switch certainly appeared to us to be more rapid in action than the ordinary electromagnetic switch, and this was stated to be the case by the engineers in charge.

Electrolytic arresters are now almost universal, and we found the common practice was to charge them every other day. With regard to telephone interference complete neutralisation of induction is produced by transposing the transmission wires if the length of the line corresponds with a complete number of revolutions of any one wire of the line; if the telephone wire is transposed twice as often as the transmission line the electromagnetic induction is neutralised not only on the whole line but on each section between two transposing towers.

Delta connection is more common than star and was stated to be the most satisfactory. In spite of this, star would seem to be the best arrangement on general grounds. Breakdowns were usually caused by ice and snow on the transmission line rather than at the power stations. The induction regulators were usually operated automatically by direct-current motors. Transformer tapping regulators were hand-operated. Professor Schwartz's account of the latest results obtained for the dielectric strength of air is very interesting and tends to confirm the belief that the dielectric strength of air in bulk is very much lower than 38 kilovolts per centimetre. The figures for R given in the paper are derived from experiments made at the University of Liverpool on the brush discharge from a wire in a concentric tube. They are also confirmed by experiments made by Professor H. T. Ryan at Cornell University. Professor Schwartz's account of his experiments on the behaviour of steam blown against a high-tension wire is very interesting indeed. We presume that his wire was charged with alternating current. It appears to give a striking illustration of the way in which the ions are shot away from the charged wire. These ions would presumably act as nuclei on which the steam would condense and thus be rendered visible.

Professor Schwartz's figures of the strength of porcelain are very interesting. The porcelain in the Locke insulator, however, is not in simple tension, and as the method of fixing it to the cap by cementing ensures a very even distribution of stress, it gives a very strong construction. The most usual cementing material appeared to be neat Portland cement, which is practically the only material used in cementing together the different parts of built-up insulators. The factor of safety of these lines is not large: on the highest voltage ones it is probably not greater than 2 to 2·5 for the insulators and considerably less for brush discharge. Shut-downs frequently occur, due to the deposit of snow and ice on the lines combined with a strong wind.

Professor Marchant and Mr. Watson.

Dr. Rosenberg states that with large asynchronous generators it is not only necessary to bring them up to speed before switching in, but also to have them in phase. This surely is incorrect, for an ordinary squirrel-cage machine cannot be said to have any "in-phase" position at all. He refers to the surge which would be caused by throwing such a machine unexcited on to the circuit, but this would probably not be any greater than if a transformer of the same size were suddenly switched on. He refers also to the bad regulation of these machines and the impossibility of controlling them. It is true that an asynchronous machine connected to a circuit without any other machines and excited simply by the charging current of the line would probably not give very good results, although by suitable design the inherent regulation could, for non-inductive loads, be made equal to that of an ordinary shunt dynamo. If, however, it is steadied by synchronous machines connected to the network it becomes quite a satisfactory piece of apparatus. If the driving turbine is not provided with a governor it will simply give a constant output to the circuit, running always at a speed above synchronism equivalent to the full-load slip, while the voltage of the system will be controlled by that of the synchronous machines. We did not actually see any asynchronous machines acting as generators pure and simple, but we saw quite a number of the asynchronous exciter sets which are mentioned in Mr. Lee's contribution. We also understand that the Interborough Rapid Transit Company, of New York, have installed a 5,000-k.w. machine of this type.

Mr. Pearce has referred to the question of capital costs. In most hydro-electric stations these are considerably higher than in steam turbine stations. The cost of prime mover, dynamo, transformers, and switchgear will be rather greater for the steam plant than it is for the hydraulic ones. In considering the relative capital costs the expenditure on hydraulic works, pipe-line, etc., must be set against the cost of boilers. In almost every case the hydraulic work is much more expensive, though it is conceivable that with particularly favourable conditions and large powers the hydraulic station might be the cheaper of the two. The cost per kilowatt of the new Winnipeg station will, it is estimated, be very little in excess of the cost of the most modern steam turbine station. For the case quoted in the paper the length of transmission line was about 50 miles. The cost of electrical energy per B.T.U. is usually higher in America than in England, though the charge for power purposes at Niagara was only £2 per horse-power-year. Underground systems are never met with outside the large towns, so that the extension of an underground cable system by an overhead line is a case which has not received any consideration. We agree that 25 cycles is a much more satisfactory frequency for general purposes than 60 cycles. We were greatly interested in Mr. Walker's most valuable contribution to the discussion; shut-downs do occur, and occur quite frequently, due to the overhead line, but the number that would occur if any underground system were laid down

as rapidly as the overhead system has been is difficult to imagine. The climate of San Francisco is very foggy during the summer and autumn, and some trouble has been caused by damp on the insulators, but the difficulties have not been at all serious. The question of long-distance distribution is, we believe, largely a matter of wayleaves, and we hope that more members who have had experience in this connection in England will give the cost they have incurred from this cause. Professor Marchant and Mr. Watson.

Mr. Chamen refers to protection against lightning. The overhead earthed wire not only tends to protect the line from direct lightning stroke, but also screens it from the effects due to electrostatic induction. Lightning seems to cause much less trouble at 100,000 volts than on transmission lines working at 20,000 or 30,000 volts. There was considerable lack of confidence among station engineers in any form of lightning arrester as a protection against direct lightning stroke. In reply to Mr. Worrall, we can only give the practice in America. The water-jet arresters, unless the water is not very clean, appears to give quite ineffective protection against lightning, although in the case of a system running entirely insulated from earth without any grounded point they may serve to prevent the accumulation of any static charge on the line or apparatus.

Mr. Fleming refers to the limit of pressure above which suspension insulators should be used. It is quite likely that it may be found good practice to have suspension-type insulators for lower voltages than that for which they have hitherto been employed. The suspension insulator is a comparatively new device, and it has therefore not been fitted on any of the 20,000- or 30,000-volt plants. Mr. Mallinson asks whether guard nets are required in America. They are only employed where a line crosses a very busy road, and are the exception rather than the rule. The requirement of guard nets in this country where a transmission line crosses a little used footpath in a remote mountain district seems somewhat unreasonable. In reply to Mr. Harlow, there are very few cases where the transformers are tied straight through. High-tension switching is the rule, and is absolutely necessary where duplicate lines are installed. The 110,000-volt plant of the Ontario Power Company is not yet installed although the plans have been prepared.

The Chairman refers to the question of long-distance transmission. This is really a question of the relative cost of carrying coal and electrical energy. Mr. Walker has pointed out in the discussion that the efficiencies of the two methods of transmission are quite different and very much in favour of electricity. The cost of land for the transmission line was not merely the cost of the patch of land on which the pole stood, but of all the land under the line for such a width as was considered necessary to ensure sufficient protection against falling wires. The chief fuel used on the Pacific Coast, both on the railways and in the power stations, was Californian oil.

AN IMPROVED TYPE OF POINT CONTROLLER FOR ELECTRIC TRAMWAYS.

By J. P. TIERNEY, Associate Member.

(*Paper received from the* DUBLIN LOCAL SECTION, *November* 4, *and read at Dublin on December* 9, 1909.)

The number of different routes on a modern tramway system and the consequent number of points to be traversed by a car on any route renders the operation of the points a matter of some importance. The stoppage of every car while the conductor gets off and sets the points becomes impracticable on a busy system, and the provision of stationary pointsmen about the roads is an expensive alternative. Hence some method is evidently needed whereby the control of the points shall be in the hands of the motorman, who thus would be in a position to determine whether the car should maintain its direction or be switched off to another route.

The subject of automatic point controllers is one which has engaged the attention of inventors since the advent of electric traction. One of the first forms of electrically operated point controllers was brought out in Detroit, U.S.A., as far back as 1892, and since that date numerous applications have been received at the Patent Offices throughout the world, but few have been tried. Judging by the Patent Office applications, the subject has been receiving an enormous amount of attention during the past five years. The reason why so many designs did not get beyond paper appears to be due to the fact that the inventors when designing their apparatus were not in possession of the difficulties to be met with, nor aware what conditions their apparatus should fulfil.

An electrically operated point controller must satisfy a variety of conditions.

It must be approved by the head of every section of the tramway undertaking on which it is to work; the electrical engineer who is responsible for the power supply, insulation of the line, etc., must be satisfied that the apparatus will not be a menace to the safe working of his end of the business; the local authority must be satisfied that the apparatus is not a street obstruction nor dangerous to vehicles, horses, etc.; the permanent-way engineer must be satisfied that the apparatus will not hamper, or in case of failure obstruct the points.

Last, but not by any means least, the traffic department must be satisfied that the apparatus will answer all the requirements of the

service, and possess the necessary flexibility to cater for all deviations of traffic.

Before proceeding to describe what we call the standard design of our apparatus which is now placed on the market as the "Tierney-Malone Point Controller," some references to the various forms which this apparatus passed through before reaching its present state will probably be of interest to the association.

Experiments were started by Mr. Malone and myself in September, 1902, with a form of apparatus which in the light of recent designs may appear cumbersome and crude; however, the fact remains that it performed its work satisfactorily from the time of its inception at the London Bridge Road Junction, Dublin (Dublin United Tramways Company), in May, 1903, until replaced by an improved and cheaper pattern some months later.

This first apparatus consisted essentially of two parts :—

1. Car equipment.
2. Street equipment.

The car equipment consisted of an electromagnet placed in a position midway between the two car motors and centrally across the track. It was of the two-pole type, and was hung vertically; the two poles facing downwards were elongated in shape and fitted with long shoes so that the period of time the magnet exerted its influence on the street switch-box was extended as much as possible. This magnet was energised at will by the motorman of the car.

The street equipment consisted of two switch-boxes, one placed before and one after the point; these consisted of a cast-iron box with a manganese steel lid under which was hinged an iron armature connected to mechanism for closing the circuit. When the magnet on the car passed over this switch-box it exerted no influence on the cover of the switch-box, the cover being non-magnetic, but lifted the iron armature beneath, which closed the circuit from the trolley wire to an electromagnet fixed in a cast-iron box at the point. This electromagnet then operated the point. The circuit of this electromagnet was broken immediately the car-magnet passed from over the switch-box. When the car had passed through the point the magnet on the car passed over the second switch-box, which switched the current into a second electromagnet at the point, which returned the point to its original position. If a motorman did not wish to operate the points he did not energise the magnet on the car.

The main drawback to this design of apparatus was the heavy initial outlay for the magnet on each car.

This apparatus was superseded by a design consisting of contacts fitted to the trolley wire which performed the function of the street switch-box, and by the contacts on the trolley heads of the cars which performed the function of the car-magnet.

The trolley head of each car was fitted with an insulated contact

which the motorman could make electrically alive at will. A contact strip was mounted on the trolley wire some 50 ft. before the point. This strip was insulated from the trolley wire and was connected to an electromagnet fitted to the point. If the motorman of the car desired to operate the point he closed the switch on his platform, thereby making the contact-piece on the trolley head alive. When the trolley of the car passed under the contact strip on the line the contact-piece on the trolley head made contact with the contact strip on the line, thereby sending a current from the car through the contact-piece on the trolley head, the contact strip on the trolley wire, and the electromagnet at the point. This electromagnet being thereby energised operated the point; when the car had passed through the point the trolley head of the car passed through a second contact strip on the trolley wire identically similar to the first. This second contact strip was electrically connected to a second electromagnet placed in the same box as the former at the point. The car thus sent a current through the second electromagnet which returned the point to the original position.

An alternative form of this type was designed to permit the running of trailer-cars, and consisted of the two contact strips being placed side by side and on opposite sides of the trolley wire about 50 ft. before the point, each strip being insulated from the other, and from the trolley wire, and each strip connected to one electromagnet at the point. The trolley head of the car was fitted with an insulated contact on each side, the motorman by means of a switch on his platform being empowered to make either but not both electrically alive. Thus either contact strip on the trolley wire and either electromagnet at the point got the current, and the point was operated accordingly in the required direction.

In the former case the points were always set for one particular route, and in the latter case the car on each route operated the points for themselves, and did not shut the points back after passing through.

These latter forms worked very satisfactorily in actual practice from August, 1903, to September, 1906, but possessed the disadvantage of requiring a special attachment in the form of these trolley head contacts above mentioned being fitted to every car. This constituted an item of expense which was really of more consequence on small systems with a small number of points than it was on large, as the number of cars per point to be fitted was excessive on the latter.

Being fully cognisant of this drawback, we directed our subsequent endeavours towards bringing out a design of apparatus which required no alteration of or addition to the cars of the service. This we accomplished, the details of the design of the apparatus encountering several minor changes before reaching its present form, the most notable change being the substitution of one large box containing all the equipment on one side of the point for the two small boxes, one on either side of the point, each containing half the apparatus.

I will now proceed to describe the standard equipment as it is now

working on several systems, including Dublin, Belfast, Newcastle-on-Tyne, Salford, Hull, Birmingham, Stoke, and Bristol.

The method consists in having each point always set for one particular line; the cars on this particular line do not move the point, but the cars going on the other line always move the point for themselves and set it back again after they have gone through.

It is equally applicable to all systems of electric traction, whether operated on the trolley, conduit, surface-contact, or accumulator systems.

Its principal advantages are :—

1. Motormen are able to see the point moving before they come up to it.
2. If the current should leave the line when the wheels of the car are going through the point, the point will not spring over, as it does not depend on the current for keeping it in any position.
3. The fact of a point being fitted with the apparatus does not in any way prevent the point being operated by the ordinary bar should occasion arise.

I will describe the apparatus in two sections :—

The Point Equipment

consists of a cast-iron box placed next to the point, the cover of this box being flush with the street surface. This box contains two specially designed stopped solenoids (one series and one shunt) placed side by side. A steel spindle is mounted vertically inside the box. This passes out through a packed gland to an outside chamber of the box. Mounted on the spindle inside the box is a lever having equal arms on each side of the spindle. This lever arm is at such a height that the nose of one solenoid plunger pushes against one arm of this lever, and the nose of the second solenoid plunger pushes against the second arm of this lever. On top of this vertical spindle in the outside chamber is mounted a lever arm, which is connected by a rod to the tongue of the point. Thus, when one solenoid is energised, it pushes one arm of the inside lever, thereby giving a turning movement of about 15° to the vertical spindle; this in turn operates the outside lever arm, and thence the tongue of the point. When the other solenoid is energised, it pushes against the other arm of the inside lever, thereby giving a turning movement in the opposite direction to the vertical spindle and lever arm, consequently shifting the point in the opposite direction.

The inside of the box containing the solenoids is perfectly watertight, the connection to the outside chamber being by the vertical spindle through the packed gland. As this spindle only turns through an angle of 15°, it is an easy matter to keep the gland watertight. A watertight joint between the cover and the edges of the box guards against water coming through in that direction. The principal advantage

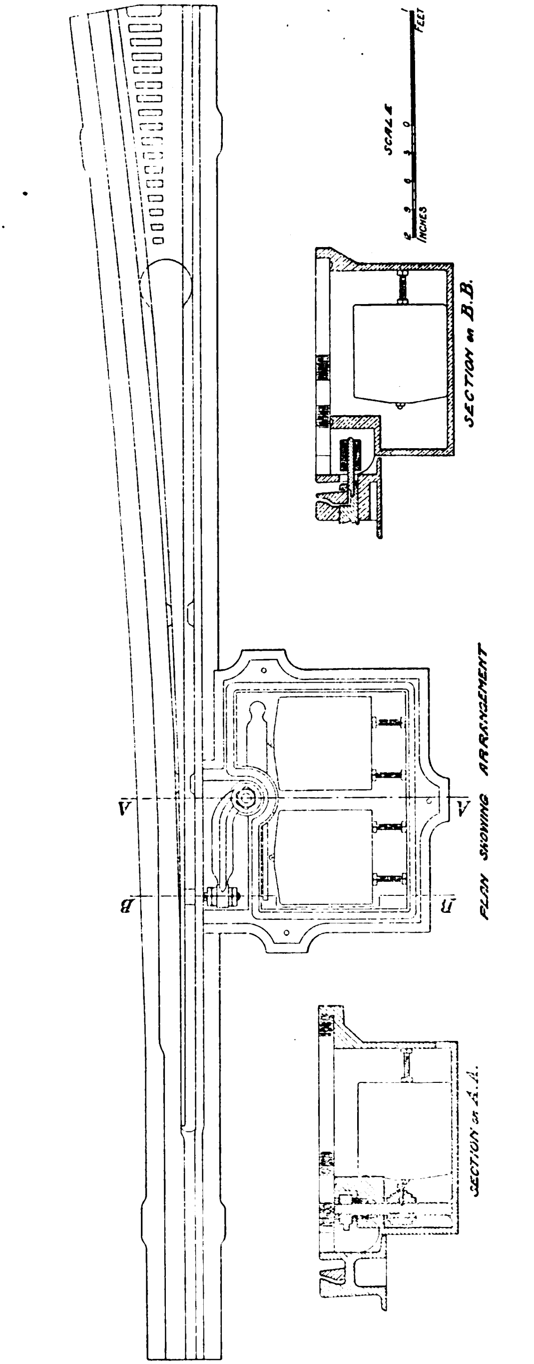

FIG. 1.—Plan of the Point with the Street Box containing the Solenoids attached, also sections through same.

of this design lies in the fact that there is not one mechanical joint in which wear may take place. There are no holes or pins to wear. The inside lever is securely keyed to the vertical spindle, inside the box, and the outside lever is securely fixed to the top of the vertical spindle, these three being for all practical purposes the one piece.

Wear of any kind would greatly injure the efficiency of the apparatus, as it would increase the air-gap of the solenoids necessary to operate the point, thereby losing power practically fourfold on account of the law of the pull of an electromagnet.

The solenoids used are of the stopped type, but instead of the plungers pulling their work after them when sucked into the coil, as is the general practice, the stop of the solenoid is bored out, and a brass rod, screwed into the plunger, passes through the stop. By this means the solenoid plungers are used to push instead of to pull their work. This arrangement has the advantage that the plunger rod, pushing against the inside lever arm, does not necessitate alignment or levelling, and further dispenses with the necessity of a mechanical joint between the solenoid plunger and the lever. The solenoid coils are hermetically sealed, and are further protected by the cast-iron casing of the solenoid, which is also waterproof in itself. Thus the winding is triply protected.

The Overhead-line Equipment.

The overhead-line equipment consists of two contacts. The first, or series contact, is placed about 50 ft. in front of the point. This gives the driver full opportunity of seeing that the point has been properly operated before he goes through; the second, or shunt contact, being placed at a suitable distance after the points. The series contact consists of a pair of inverted ramps, secured to the trolley wire. Between these ramps is a contact strip or centre-piece, insulated from the trolley wire. These are so arranged that a trolley passes along the underside of the ramp (and in doing so leaves the trolley wire), and from the ramp it passes on to an insulated inset, thence along the centre contact strip, under another insulated inset, along the second ramp, and thence on to the trolley wire again. By means of two bridging-pieces over the insulated insets there is no part of this contact from which the trolley cannot get current, so that, no matter what position a car stops in, it will have the necessary current to start off again. This centre contact strip is electrically connected to the trolley wire, through the series-wound solenoid placed in the street box at the point. Thus it will be seen that whatever current the car is taking from the line when the trolley is passing under this insulated contact strip will pass through the series solenoid in the street box at the point as the trolley head makes electrical connection with the centre contact strip. The second, or shunt contact, consists of an ordinary ear with two hubs attached in the usual manner under the trolley wire. Each of these hubs carries a special insulator, and these

in turn carry between them a contact strip. This strip is insulated from the trolley wire, and is so suspended and placed that, when the trolley head of the car is passing under the ear, the side of the trolley head will rub against and make contact with the contact strip on the line. This contact strip is connected to the shunt solenoid in the street box through a suitable switch and fuse placed in a control box on the nearest street-pole. The other end of this solenoid is connected with the rail.

An alternative method of constructing this contact is to have it uninsulated from the trolley wire and to mount on it a spring contact which connects to an upper insulated fixed contact when the former is lifted by the trolley head, the upper contact being connected to the shunt solenoid.

A control box on the nearest pole contains three switches and three fuses. Two switches and two fuses enable the series solenoid to be entirely disconnected from the overhead-line contact when the points are being examined or overhauled. The third switch and fuse performs the same operation for the shunt solenoid. In case of a fault developing on a magnet or a cable going to earth, the fuses protect the apparatus from damage and also protect the line from being grounded.

Two 260-volt 16-c.p. lamps in the control box connected in series with each other are permanently connected between the wire connecting the second, or shunt, contact with the shunt solenoid and earth, and are therefore permanently in parallel with the shunt solenoid, thereby acting as a discharge resistance for the solenoid coil, and take up the back E.M.F. which would otherwise be set up owing to the solenoid being open-circuited. In the case of the series solenoid this function is performed by the bridging-pieces, as by their operation when the trolley of the car is leaving the centre contact strip it makes contact with the bridging-piece on the trailing end of the first contact before leaving the centre contact strip. This has the effect of short-circuiting the series solenoid before open-circuiting it, and consequently discharging the back E.M.F.

Method of Operation.

When the driver of a car approaches a point which it is necessary for him to move, he keeps his car controller on one of the operating positions while the trolley of his car is passing under the first or series contact. When the trolley of the car passes, it will draw its current from this insulated contact, thereby drawing the current the car is taking through the series solenoid at the point, which solenoid, on becoming energised, will move the point to the desired position. When the trolley of the car has passed from under this contact, the current is cut off this solenoid. The car having passed through the point, the trolley passes under the second, or shunt contact, which is then made electrically alive, thereby sending the current to the shunt solenoid, which throws the point back to its original position. If drivers do not require to move the point they keep their car

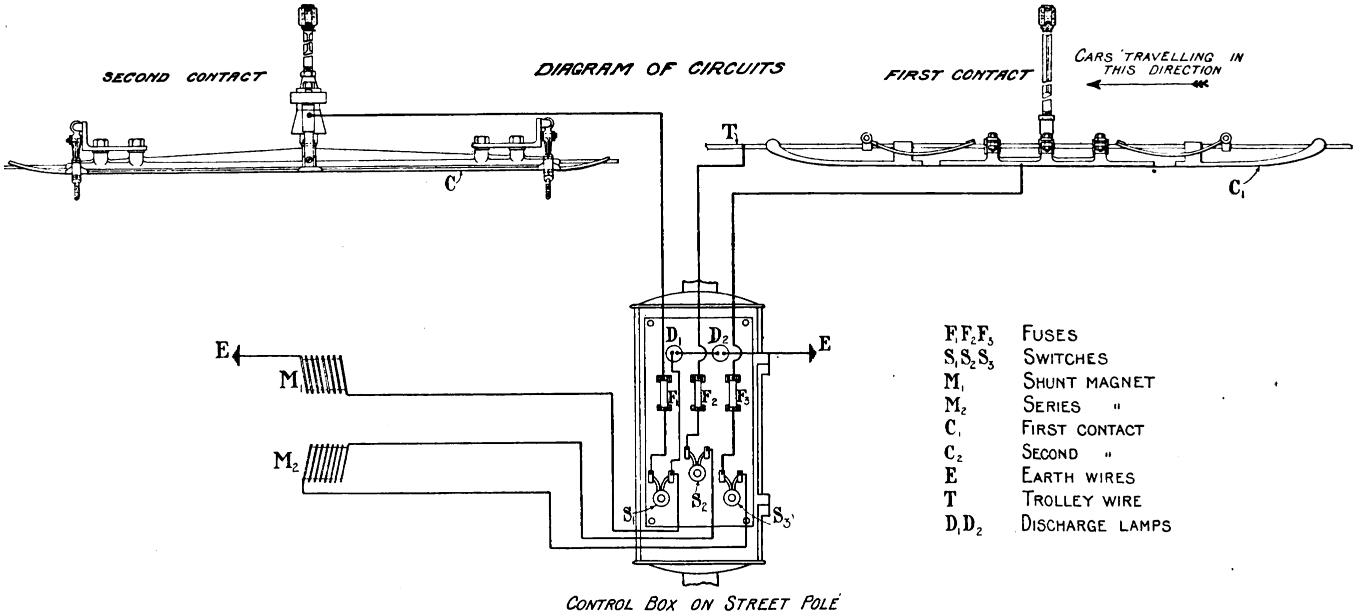

FIG. 2.—Side-view Elevation of the two Overhead Contacts on the Trolley Wire, the first being Series Contact and the second Shunt Contact. The Control Box on the Street Pole contains the cut-out switches and fuses and the general wiring connections.

controller on the "off" position while the trolley is going under the first contact. It is immaterial whether the car controller is in the "on" or "off" position while passing under the second contact, either in the case of a car which has operated a point for itself, and requires to close it, or in the case of a car which has passed through the point in the direction for which the point is set.

I may here add that the length of the insulated contact strip, first contact, is only 18 in., so that it does not in any way inconvenience the motormen who require to drift through without power.

If a motorman were forced to stop with his trolley under the first contact, a thing which need not occur except through want of judgment on his part, he would naturally take the starting current of his car through the series magnet, and thus operate the point. If he did not require to shift the point for his route, he would then bring the front of his car close to the point, and operate the point by the ordinary points bar. As the first, or series contact, is only 18 in. long, this rarely happens, and need not happen at all.

For Continental working, where the use of trailer-cars is extensive during the rush hours of the day, this method of working the points, which answers all the conditions in Great Britain, would not apply, as the shutting back of a point by a car with a trailer attached would cause the motor to take one road and the trailer the other, whereas, if this second contact was placed so far ahead as to permit all the trailers to pass through before the point were shut back would cause considerable delay during the slack period of the day when the single motor-cars would be running.

To meet these conditions we have altered the design in the following details :—

There is only one overhead contact instead of two, that one being the same identically as described above as the first or series contact, and being placed as before, 50 ft. in advance of the point.

Each car requiring to open the point does so as explained above, but does not shut it back—*i.e.*, the car on each road makes the point for itself.

This design possesses all the advantages of the one I have just described, and, in addition, it is specially designed to facilitate the running of trailer-cars to an unlimited extent, and it is equally efficient and successful for the operation of single motor-cars as it is for motor-cars with trailers attached. There is only one overhead contact on the trolley wire and only one solenoid. The overhead-line equipment, as just mentioned, consists of only one contact, which I have described already.

THE POINT EQUIPMENT

consists of a cast-iron box placed next to the point, the cover of this box being flush with the street surface. This box contains one specially designed stopped solenoid which is pivoted on the bottom of the box in such a way as to take either of two positions, according to the position of the point tongue. A steel spindle is mounted vertically inside

the box. This passes out through a packed gland to an outside chamber of the box. Mounted on the spindle inside the box is a lever having equal arms on each side of the spindle.

The boss of this lever arm carries a tilting arm which projects over the top of the magnet and extends to the back of same. A recess at the back of this tilting arm carries a spiral compression spring, inside of which is a spindle which has a roller fixed at its extremity. This roller bears against a friction plate which is cast on the top of, and in the centre of, the magnet. The lever arm above mentioned, which is fixed on the spindle inside the box, is at such a height that the nose of the solenoid plunger pushes against one arm of this lever when the magnet is in one position, and against the second arm of the lever when the magnet is in the alternative position. On top of this vertical spindle in the outside chamber is mounted a lever arm which is connected by a rod to the tongue of the point. Thus when the solenoid is in one position and is energised by the current, its plunger pushes against one arm of the inside lever, thereby giving a turning movement of about 15 degrees to the vertical spindle. This in turn operates the outside lever arm, and thence the tongue of the point. This movement of the vertical spindle causes the tilting arm which is affixed thereto to rotate through the same angle, and in consequence causes the roller to travel along the friction plate on the top of the magnet from one side of the latter past the central point of the magnet to the other end. In so doing it compresses the spiral spring fixed on the roller spindle. When the current is cut off the solenoid, the pressure between the nose of the plunger and the inside lever arm is in consequence relieved. The compression spring then relieves itself by pressing the roller against the end of the friction plate against which it is now bearing, and in doing so turns the solenoid on its pivotal mounting from its first position into the second position, which is such that the nose of the plunger is brought in front of and in contact with the second or opposite arm of the inside lever. When the solenoid is next energised by the current of another car its plunger pushes against the second or opposite arm of the inside lever, thereby giving a turning movement in the opposite direction to the vertical spindle and outside lever, and consequently shifting the tongue of the point in the opposite direction. This movement of the vertical spindle causes the tilting arm attached thereto to turn through the same angle as itself, and in so doing causes the roller to travel along the friction plate from the end against which it now bears to its former position, and in doing so, as before, compresses the spiral spring. When the current is cut off the solenoid the pressure between the nose of the solenoid plunger and the inside lever arm is relieved. The compression spring then relieves itself by pressing against the friction plate, and in doing so turns the magnet on its pivotal mounting back to its former position.

Thus each time the solenoid is energised the point is operated in the opposite direction to the previous operation, or the solenoid is always in such a position that when it is energised it will operate the

point. Likewise the operation of the point by hand will turn the solenoid.

The same remarks as to mechanical parts in which wear may take place applies in this case as it did in the other design.

Method of Operation.

When the driver of a car approaches a point which it is necessary for him to move, he keeps his car controller on one of the operating positions while the trolley of his car is passing under the contact on the trolley wire. When the trolley of the car passes underneath it will draw its current from this insulated contact, thereby drawing the current the car is taking through the solenoid at the point, which, on becoming energised, will move the point to the desired position in the manner explained above. When the trolley of the car has passed from under the contact the current is cut off the solenoid. The solenoid will then turn on its pivotal mounting, as before described, so that when it is next energised it will operate the point in the other direction.

If the next car following is going in the same direction, the point being set right for him, the motorman will keep his car controller in the "off" position while the trolley is going under the contact, and thus draw no current through the solenoid and not operate the point. If, on the other hand, the car following wishes to take the other route, the point being against him, the motorman will keep his car controller on one of the operating positions while the trolley is going under the contact on the trolley wire, thus energising the solenoid, which is now in a position to operate the point in the reverse direction. Thus any motorman requiring to operate the point keeps his current on, and any motorman not requiring to operate it keeps his current off. The point is not set back after the passage of a car.

The length of the insulated contact strip is only 18 in., so that it does not in any way inconvenience the motorman who requires to drift through without power.

For Conduit Tramways.

The contact above mentioned as being attached to the overhead trolley wire is in the conduit system mounted on one of the conductor rails in the conduit. The contact is specially designed to go on the conductor rail, and in no way impedes the passage of the car-ploughs.

The Operation of the Overhead-line Frog.

The overhead frog on the trolley wire can be operated in connection with the track point if desired, or can be operated mechanically by automatic mechanism.

It will thus be seen that this point controller differs from other designs, inasmuch as when a car has operated and passed through a point the car does not throw the point back, so that this controller

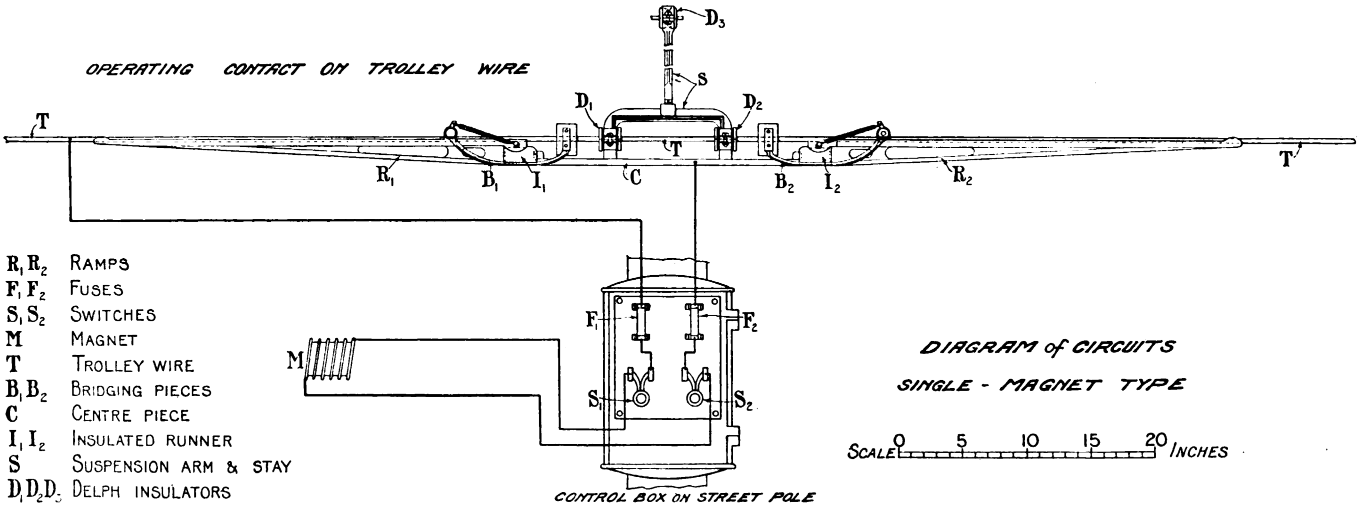

FIG. 3.—General Diagram of the Wiring Connections of the One-magnet type of Point Controller, with side elevation of the Overhead Contact on the Trolley Wire, the Control Box on the Street Pole, and the Magnet Winding.

permits every car to operate a point in whatever direction the driver chooses. It also permits the running of an unlimited number of trailer-cars if desired, which is not permitted when the point is shut back after the passage of a car.

After the magnet has moved the point it does not hold it over, but the point is then an ordinary point, and any failure of current does not in any way affect the passage of the cars or cause the point to spring back.

At night the position of the point tongue can be shown to the motormen by coloured lights on the nearest street-pole.

Discussion.

Mr. Tweedy.

Mr. R. N. Tweedy: I have heard that trouble has been experienced in some towns with burnt-out solenoids and overloaded fuses. I should like to know what the normal working currents of the two magnets are. It seems that the current passing through the series magnet depends entirely upon the action of the motorman.

If he chose to go under the contacts with the car-controller on the full series position, for instance, the point controller and its fuses might suffer. Then, in the Tierney-Malone system the series solenoid is subjected permanently to the full-line potential to earth, and this seems likely to cause breakdown sooner or later, however well the underground box is designed to keep out water. I should like to call attention to a new system which is interesting because it appears to be a development of one of Mr. Tierney's earlier ideas, and, whether it works in actual practice or not, it apparently overcomes the difficulties —if such there are—which would seem to stand between the Tierney-Malone controller and perfection.

The chief merits of the new system as compared with the Tierney-Malone system are said to be :—

1. The line potential is cut off the working coil except during the moment of operation.
2. There is only one overhead contact.
3. There is only one magnet, and the core is coupled direct to the point tongue.
4. The working current in the point solenoid is small, and does not depend upon the current taken by the car.

Briefly, the working parts consist of an overhead contact, two small directional solenoids, which are placed in a box on a tramway standard, and the single working solenoid which is placed, of course, in a water-tight box in the roadway.

The current in the working coil is independent of the car resistance, and it would be constant; therefore, drivers wishing to move the points would not be restricted to the use of one or two notches of the controller, and there should be an absence of blown fuses and burnt-out solenoids, which is said not to be the case with other systems.

The overhead contact device would consist of two sides, insulated from each other and from the trolley wire. Mr. Tweedy.

As the trolley wheel passes under the contact strips it bridges them and is separated from the trolley wire.

The two independent small directional magnets control a common armature, and, according as one or the other is the more powerful, that portion of the point magnet winding is energised which is connected to the contacts and is then closed through the directional armature.

Whereas the Tierney-Malone series magnet is in series with the car which is operating the points, and thus is subjected to any current which the car may happen to be taking at the time, the single operating coil of the new system takes a constant and very trifling current—1 to 1½ amperes.

Mr. G. F. PILDITCH: I should like to know whether much trouble has been experienced through dirt and stones getting in and interfering with the satisfactory working of the points; also whether it is usual to clean them out at regular intervals, and if so, what is the general practice? I should also like to know the pull in lb. weight (or push in this case) required to move the average point under ordinary working conditions, and the maximum force the solenoid plungers are capable of exerting. Mr. Pilditch.

Another question I should like to ask is whether, in the event of the circuit through the series solenoid being broken for any reason, there is much trouble from arcing when the trolley leaves the live wire at the insulating piece between the wire and the first contact? It is possible for a heavy current to be flowing at the time, particularly if the car is travelling uphill, in which case a pretty bad arc would result. In the case of a damaged coil on a busy section this might occur many times before the circuit could be completed.

Mr. W. TATLOW: I should like to ask whether the lighting current for the cars might be large enough to cause the series solenoids to operate on the points. Mr. Tatlow.

Mr. P. S. SHEARDOWN (*communicated*): The great difference between Mr. Tierney's type of point and others that have been brought to my notice is that in his the operating gear is practically part of the point instead of operating through a number of levers, etc.; by this means a direct pull is got on the point without the disadvantage of many moving parts to get out of adjustment. Mr. Sheardown.

With regard to its operation in practice, I need hardly say the Dublin Tramway Company did not equip the number of points they now have in operation until the invention had been given a thorough practical test.

The way the arrangement has been simplified since its original stage is remarkable. In its first form it was necessary to carry a considerable equipment on each car, which would have been a very costly matter, afterwards this was reduced so that there was only an attachment to be made to every trolley head. Now the car equipment has been eliminated altogether, and the system generally seems to be about as simple as one could wish for.

Mr. Tierney.

Mr. J. P. Tierney (*in reply*): With reference to Mr. Tweedy's remarks about burnt-out solenoids and overloaded fuses, during the five years this point controller has been in service I have not heard of any instances of trouble of this kind, and I think that if the conditions are analysed it will be seen that no trouble need be expected. In order to burn anything out heating must first take place, which involves a time element; except, of course, in such cases as a short circuit causing very heavy, excessive currents to flow through a circuit. Owing to the short length of the overhead operating contact—viz., 18 in.—the period of time during which current is flowing through the solenoid never exceeds a small fraction of a second. I think, therefore, that even at an excessive current density no urning out of the solenoid would take place. I may point out that my main difficulty at the start was to design a solenoid which would build up and give its pull in the small time available. The series magnet is designed to give its full pull with the average current taken by the cars on the system when on the first or second controller position and when travelling about 4 miles per hour. The satisfactory working limits are very wide and need not be considered. There are several point controllers in existence which are so designed that the current remains on the operating solenoid from the time the trolley of the car first comes under the operating contact until the car has cleared the point. In such systems if a car for any traffic reason were forced to stop between these two spots current would be flowing through the operating solenoid until the car had cleared the points. I rather think any trouble of burnt-out solenoids which Mr. Tweedy has heard of must have occurred in that way. As regards going through the contact on the full series position, this repeatedly happens, but no trouble is caused because the speed of the car is very much higher on the full series position than on the first or second position, and therefore the back E.M.F. of the car motors is increased, thereby reducing the current which flows through the point solenoid to almost the same value as if the car had been on the first or second position of the controller. The fact that the series solenoid is permanently subjected to the full-line potential to earth has never caused any trouble, and should not do so, any more than the thousands of miles of feeder cables under full working pressure year in and year out all over the United Kingdom. With reference to the system described by Mr. Tweedy, I would ask members to contrast it with our latest design of single magnet point controller, which has only one magnet, whereas the design shown by Mr. Tweedy has three. I would further point out that delicate switch or relay mechanism does not give the most satisfactory results when placed in a box on the street; the absence of these is a point of superiority in our design. As regards the current taken by our series solenoid, this is immaterial from a consumption point of view—first, because of the very short time; and, secondly, because it is only the car current momentarily diverted. In answer to Mr. Pilditch, dirt and stones do not cause much trouble. The majority of tramway junctions are paved from kerb to kerb, and

hence there are no loose stones about. No special precautions are taken for cleaning. A man visits each point once a day on his rounds and cleans the point thoroughly. The average pressure required to operate a point under average conditions is about 150 lbs., and a factor of safety of about 2 is allowed in the solenoids. If the circuit through the series solenoid gets broken the operating contact is then the same as a section insulator; the point must then be operated by hand. In reply to Mr. Tatlow's question *re* the car lighting affecting the solenoid, the largest lighting current I have so far met with on a car was twenty-four 16-c.p. carbon filament lamps, about 2¼ amperes. This current is not sufficient to energise the series solenoid to exert a pull which would affect the point tongue. I am greatly indebted to Mr. Sheardown for assistance in the development of the design of our point controller. Mr. Tierney.

CONTINUOUS-CURRENT BOOSTERS AND BALANCERS.

By W. ARTHUR KER.

(*Abstract of paper received from the* GLASGOW LOCAL SECTION, *August* 31, *and read at Glasgow on December* 14, 1909.)

In the case of a 2-wire network for a small town supplied by one feeder, the voltage at the feeding point may be kept constant by hand regulation of the dynamo or by using a booster.

A series wound booster consisting of a single generator might be adopted, the field winding being such as to compensate for the drop in both the positive and return of the feeder, and it can be wound to over-compensate for this drop, and therefore to compensate wholly or partially for the drop in the distributors themselves.

This is the cheapest type of booster, and it is quite satisfactory so long as there is only one feeder, but it cannot be used in conjunction with another similar booster and feeder unless certain precautions are taken.

In Fig. 1 is shown a network with a load of 100 amperes concentrated at a point one-fourth of the way along the network from No. 1 feeding-point. One would naturally expect that the booster feeding the point nearest to the load would carry the greater current, but the reverse is actually the case, the further booster carrying 17 amperes more than the former. This is not conducive to economy, and the system is not stable, as explained later with reference to Fig. 2. The voltage at the lightly loaded feeding-point is also lower than that at the highly loaded feeding-point.

By putting the field coils of the two boosters in parallel, the load is divided naturally, so that the feeder nearer to the load takes the greater share, but the voltage at the feeding-points is not constant, the more heavily loaded one having the lower voltage.

Two boosters of this type, whether with fields in parallel or not, do not give accurate results.

This trouble may be obviated by using double 2-wire series boosters—that is, each feeder has one booster in the positive and one in the negative. Each of these boosters must be wound to compensate for the drop in its own half of the feeder.

Fig. 2 shows two feeders connected to a network with double boosters. As a positive booster compensates merely for the drop in its

positive feeder, it is evident that by whichever negative feeder the current travels, the negative booster on that path will compensate for the drop. Boosters of this type, which just compensate for the drop in the feeders, share the load in inverse proportion to the resistance of the load from the feeding-points.

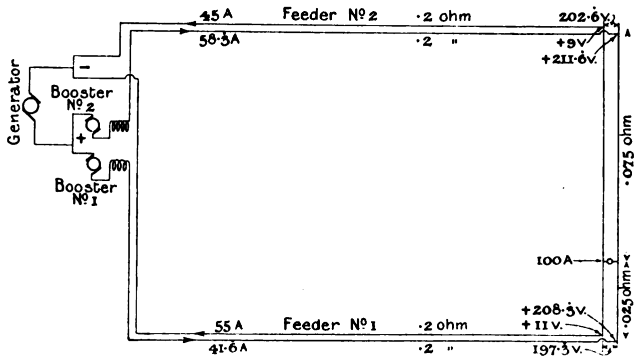

FIG. 1.

One objection to this system is that, the boosters being smaller than would be the case with a single booster, their efficiency is not quite so high, and they are more expensive.

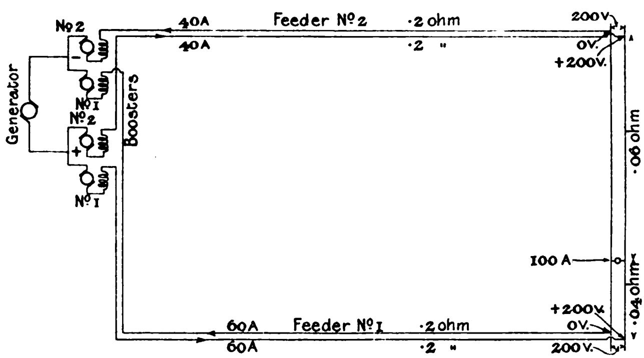

FIG. 2.

One precaution must be taken in designing boosters to run as shown in Fig. 2. They must not over-compensate for the drop in the feeder. Assume that, owing to inaccuracy of workmanship or some other cause, No. 1 booster slightly over-compensates for the drop in its feeder, while No. 2 just exactly compensates for the drop in its feeder. If, under these circumstances, No. 1 booster is carrying a heavier current

than No. 2, the voltage at the feeding-point of No. 1 increases, and therefore a still heavier current passes through No. 1, which automatically increases the voltage, until No. 1 booster takes all the load away from No. 2 booster, which may even be driven as a motor.

Of course, if the resistance of the distributing network is high, an appreciable amount of over-compensation would be required to produce this effect; but the resistance of the network is generally low, and a very small degree of over-compensation may be sufficient. One method of guarding against this danger is to equalise the currents in the field coils of the boosters, as shown in Fig. 3. Any over-compensation of one booster causing it to take a larger load passes an increased current round the field coils of the other booster, increasing its voltage, and therefore to some extent increasing its load. This does not completely

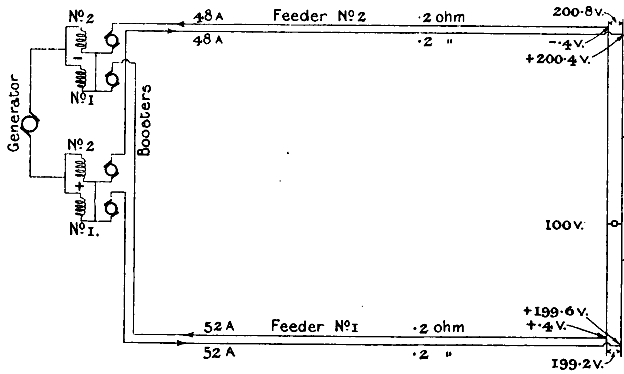

FIG. 3.

cause the boosters to divide the load proportionally, but it prevents any danger of one booster robbing the other of a large portion of its load, and it may therefore be considered stable.

It will be noted that the method in Fig. 3 gives a more equal sharing of the load by the two boosters than the method in Fig. 2, but that the voltage at the feeding-points is altered, in place of being constant at 200 volts with any load.

A better plan is to wind the boosters slightly to under-compensate for the drop in the feeders. In this case the more heavily loaded booster delivers current at the feeding-point at a slightly lower voltage than the lightly loaded booster. The latter therefore tends to give a larger current, and equilibrium is restored. The only objection to this is that at times of heavy load, when the boosters are carrying a large current, the voltage at the feeding-points is less than it is at times of light load—that is to say, when the drop of voltage in the network itself is greatest, the applied voltage at the feeding-points is least.

To meet this difficulty it is easy to raise the voltage at the station

busbars a few volts, and so raise the pressure at the feeding-points to that necessary to give the consumers the declared pressure. This raising of the busbar voltage does not in any way affect the compensation of the boosters.

In a 3-wire system it is not possible to adjust the consumers' demands on each side so that they balance, a current must therefore tend to flow in one direction or the other, in the neutral wire, and care must be taken to provide a path for this current. The usual method and the most practicable is to employ a balancer. We cannot therefore consider boosters in connection with a 3-wire system without also considering the balancers. Let us first deal with the balancer. A balancer may be placed either at the network or at the generating station, and we will later touch upon the reasons for deciding which plan shall be adopted.

A balancer consists of two similar machines with their armatures mechanically coupled together and electrically connected in series across the outers of the 3-wire system. The neutral wire is brought to the junction of the two armature windings. The two machines may be shunt or compound wound, as may be best for the particular case, and the method of exciting these coils is mentioned later.

When the balancer is connected across the mains with no out-of-balance current flowing in the neutral wire, both machines run as motors doing no work. As soon as an out-of-balance current flows in the neutral wire it divides, and part flows through one armature, driving it as a motor, while the other part flows through the other armature, which acts as a generator, returning the current to the line.

If a plain shunt-wound balancer was of 100 per cent. efficiency, and the excitation of both machines was equal, the out-of-balance current would divide into equal parts; but as there is a loss in both the motoring and generating sides, the current in the motoring side is more than the current in the generating side. In a concrete case it is necessary to allow for this difference, but for our purposes it is simpler to consider that the current divides equally, and so avoid tedious calculation.

It is obvious that to deal with an out-of-balance current of 100 amperes in the neutral wire, it is only necessary to instal two machines, each capable of dealing with about 50 amperes.

It was said above that it is necessary to provide a path for the current in the neutral wire; but the balancer does much more than this. As its name indicates, it is a means of balancing. It does not balance the current, but the pressure.

If one takes a 3-wire network having nominally 400 volts between the outers, and 200 volts between each outer and the neutral, and the pressure on the outers kept constant independently of the load, by outside means, and if one considers the case of a balancer at the feeding-point and that no current is being supplied at all, but that the balancer is running in readiness for a demand and keeping a pressure of 200 volts between the neutral and each outer, and assumes that the

balancer is shunt wound, both machines excited in series across the outers, such a balancer will run as two motors at a constant speed, and the back or internal E.M.F. of each machine will be, say, 198 volts. If now consumers suddenly switch on lights, taking 100 amperes, on the positive side only, this current will return through the neutral wire to *A*, the middle point of the two armatures. There is only one path from *A* to the negative brush of the dynamo available for this current, and that is through the balancer on the negative side, which in Fig. 4 is called *M*, the positive one being called *G*. This current will therefore try to pass through *M*, and, in so doing, to reduce its speed and internal E.M.F. *G*, however, keeps *M* running at the same speed as before, and therefore keeps up its internal E.M.F., with the result that the external E.M.F. across the brushes of *M* increases, and (as the pressure across the outers is constant) the external E.M.F. of *G* decreases and its internal E.M.F. then exceeds its external E.M.F. and *G*

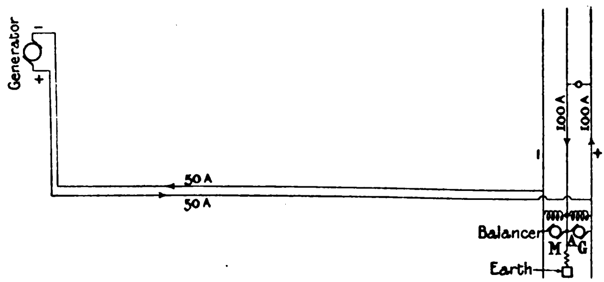

FIG. 4.

becomes a generator, taking some of the current from the neutral and passing it into the positive of the network, and, by so doing, the voltage across its brushes increases, reducing the voltage across *M* until a point of balance is obtained when *G* is taking nearly half the current in the neutral wire and the voltage between the positive and neutral is nearly equal to the voltage between the negative and neutral.

These voltages can never be the same in such a balancer with an out-of-balance current flowing, as the pressure on the positive side is equal to the internal E.M.F. of *G* minus the drop in its armature, while the pressure on the negative side is equal to the internal E.M.F. of *M* plus the drop in its armature, while the internal E.M.F.'s of *G* and *M* are identical, as they are running at the same speed in similar fields (neglecting the effect of armature reaction).

The difference in pressure between the two sides may amount to several volts, so a simple shunt-wound balancer with shunt connected directly across the outers forms a very poor automatic balancer.

An improvement to the automatic regulation may be effected by exciting *G* from the negative and neutral and exciting *M* from the positive and neutral—that is, by cross-connecting the fields of *G* and *M*.

Fig. 5 shows the arrangement. The field of *G* (which is generating) is excited from the side with the higher pressure, and that of *M* (which is motoring) from the side with the lower pressure, the speed of the set then increases and the voltage of *G* is still further increased by the larger field. This method of exciting considerably improves matters, but it does not effect a complete readjustment of the voltage.

A further improvement may be made by adding a few series turns on the field coils of each machine through which the current in the neutral is led, these series turns also being crossed.

When an out-of-balance current is flowing through the series coils in either direction it assists the shunt coils of the generating side and opposes those of the motoring side, so increasing the speed and the voltage of the generating side. It is usual to make the series coils of each machine of such a number of turns that they compensate for the armature drop in the machine.

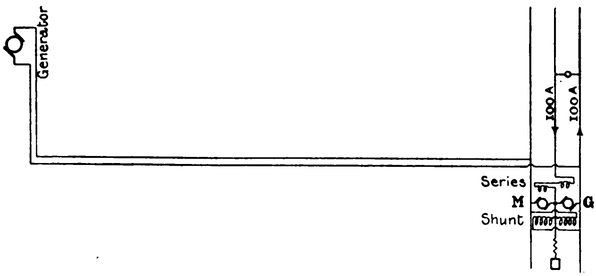

Fig. 5.

By increasing the number of series turns it is possible to over-compensate and to increase the pressure on the heavily loaded side; but this is rarely done in the case of a balancer at the feeding-point or on the network.

Such a compound balancer with coils cross-connected forms an automatic method of keeping the voltage on both sides of the neutral approximately constant.

A shunt-wound balancer with the shunts regulated by hand would have the same effect.

One may appropriately pause here to discuss the question of hand-regulated balancers against automatic balancers. A hand-regulated balancer necessitates the presence of an attendant whenever current is being supplied, that is generally for twenty-four hours a day. It requires constant watchfulness on his part to adjust the regulator as the load varies, and this introduces the personal element which most engineers endeavour to eliminate as far as possible.

The advantages of hand regulation are that with a careful attendant the exact declared voltage can be kept on both sides, and the designer of the balancer is relieved of a large amount of careful calculation, as,

if the machines are large enough for the work and can give the highest voltage necessary, no further calculations are required, as any departure of the generator from a regular voltage curve is compensated for by the regulator adjustment by the attendant. The chief disadvantage of hand regulation is the cost of attendance. In cases, however, where current is transmitted to the network at high voltage, either continuous current or alternating, and is there converted into low-pressure-continuous current, this objection no longer applies, as an attendant must be present to attend to the running of the converters, or motor-generators, who can also adjust the shunt regulator.

The advantages of an automatic balancer are, that no attendant is required, occasional visits to fill up the oil-wells and clean the machines being all that is necessary, that the personal element is eliminated, and variations of load compensated for as soon as they occur.

The disadvantages are that the machines are slightly more costly, that they are difficult to design to give accurate results, and that they must work on the straight part of the induction curve to obtain good regulation, necessitating somewhat larger machines.

A cross-connected compound balancer will stand up to any out-of-balance current and strive to keep the voltage equal on the two sides, and this may be a source of danger. If, for instance, a partial short were to occur on one side the out-of-balance current might become so large that the motoring side of the balancer would be overloaded, causing a flash-over or a breakdown of the motor. To obviate this it is well to put the series coils of the balancer in parallel with a diverter resistance and introduce a fuse, or circuit breaker, into the branch to the coils. In this case, when an excessive out-of-balance current occurs, the fuse will blow, cutting out the series coils, and the balancer will continue to run as a shunt balancer and will be able to deal with a very large current, though naturally the balance between the two sides will be bad.

To return to the subject. An automatic balancer at the feeding-point or on the network has been considered, with the voltage across the outers kept constant at the feeding-point by extraneous means. Let us now consider the method of keeping the voltage constant at the feeding-point.

In large cities it is now the custom to transmit 3-phase current to sub-stations at convenient points and there to convert it into continuous current and transmit it by short feeders to the feeding-points. As these feeders are all short and generally proportional to the load they are expected to carry, all the regulation required is effected by varying the shunt excitation of the continuous-current side of the motor-generators.

Other towns which supply continuous current direct from the dynamos to the feeders generally raise the pressure of the dynamos as the load increases, and by having more than one set of busbars and dynamos different pressures may be carried to suit the load on different feeders. In one case at least not less than seven different pressures were carried in the station at times of heavy load.

Such a system is complicated and uneconomical. It renders it difficult to run the dynamos, or any of them, at approximately their full, and therefore economical, load, and it prevents the use of a battery to assist during the peak load.

Another method of keeping the pressure at various feeding-points approximately constant is to vary the section of the copper in the feeder as the load varies, triple concentric feeders with conductors of three different sections being used. Such a system, though probably fairly satisfactory in practice, is commercially unsound. At times of light load the smallest conductor of the feeder would be used and the drop on this would be the same as the drop on the whole feeder at full load. Assuming that the drop allowed for is 10 per cent., the result is that for practically twenty-one hours out of the twenty-four 10 per cent. of the output is being wasted, whereas an average loss during these times of perhaps 4 per cent. would be experienced if boosters and single feeders had been used. To incur heavy capital expenditure for large 3-core feeders and then to allow the major portion of the copper to lie idle for the greater part of the twenty-four hours at the expense of the coal bill cannot compensate for the small loss of energy in the boosters in the other system. The complication of the switchgear necessary is another objection.

A system of boosters with a constant pressure on the busbars is much more favourable.

We will now consider our automatic compound balancer (Fig. 5) at the feeding-point, which is to be supplied with current at a constant pressure of 400 volts across the outers by means of a booster.

When there is only one booster it may be a simple single generator in one of the outers, driven by motor, engine, etc., and series wound to add automatically the pressure due to the drop in the positive and negative feeders. Such a booster is quite satisfactory so long as there is only one feeder, but, as explained before with reference to 2-wire boosters, it should not be used if there are two or more feeders. We must therefore use two separate boosters for each feeder, one on the positive and one on the negative, each compensating for its own part of the feeder. As explained before, such boosters should slightly under-compensate for the drop, so that when a second feeder is added the conditions may be stable.

A commercial booster of this type can easily be made to add voltage in proportion to the current passing through it with a maximum percentage error of 5 per cent. As the drop in a feeder is not likely to exceed 15 per cent. of the dynamo voltage the error of the double booster is less than 0·75 per cent. of the dynamo voltage. As it is unlikely that the percentage error of the positive booster is at its maximum at the same time as the negative booster is at its maximum, the actual combined maximum percentage error will be less than this amount—that is, less than 3 volts on a 400-volt supply.

Boosters of this type (double 2-wire series boosters) are quite satisfactory, however many boosters and feeders may be employed, so long

as no one of them over-compensates for the drop on its own feeder. As these boosters are generally installed at the generating station they might be hand-regulated shunt machines, as no extra attendant would be required, but the personal element would be again introduced.

So far, we have considered the case of a 3-wire network with the balancer at the network. One advantage in placing the balancer in that position is the saving of the copper in the neutral from the generating station to the balancer, and also the drop in the long neutral, due to the out-of-balance current. There is no gain or loss due to drop in the outers, as if the balancer were carried back to the generating station one outer (say the positive) would carry the whole out-of-balance current, whereas, with the balancer at the network each outer of the feeders carries approximately half that current. In the former case, however, the copper of the outers should be large enough to carry economically the whole current due to the demand from the feeder when equally balanced plus the whole out-of-balance current.

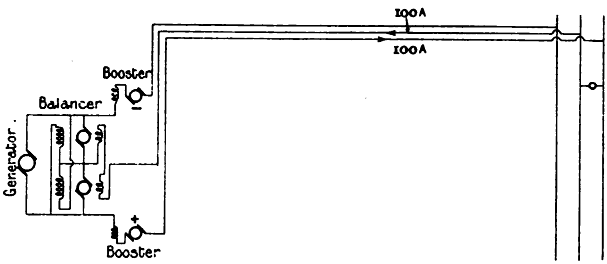

FIG. 6.

The total saving effected by placing the balancer at the network is, therefore, no neutral feeder, less copper in the outers, and saving due to drop in the neutral feeder dispensed with.

Against this must be put the objection to placing running plant anywhere but in the generating station, the cost of a special building, foundation, etc., for the balancer, and the cost of sending to oil and adjust the balancer two or three times a day.

A further objection in some cases is, that the generating station may send out feeders in two or three quite different directions, and in that case the copper of the network must be of heavy section to carry the out-of-balance current without undue loss, or two or more balancers must be installed, in which case the loss of energy running these small machines, with only a small out-of-balance current during the greater portion of the time, would be appreciable.

Probably the best plan, except in certain special cases, is to place the balancer at the generating station, and to balance the whole system at that point.

Let us take the case of a system balanced at the station with a double-series booster, and let us show in Fig. 6 such an arrangement

with a single 3-wire feeder. Each booster compensates for the drop in its own part of the feeder. With a load of 100 amperes on the positive side only, as before, the positive booster compensates for the drop in the positive feeder, the negative booster has no current flowing

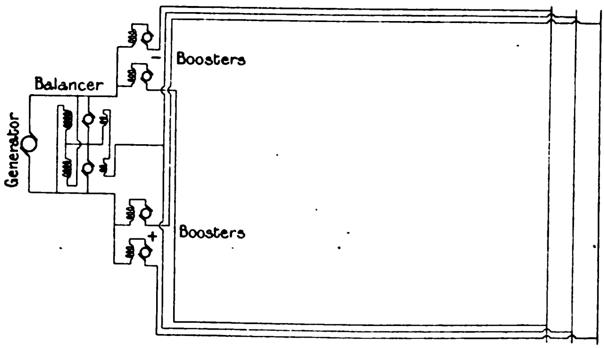

FIG. 7.

through it, and the 100 amperes return through the neutral to the balancer. It is evident, therefore, that the balancer itself must be made to compensate for the drop in the neutral, and this is generally done. If now a second 3-wire feeder with its booster is laid down and connected as shown in Fig. 7, the current in the neutral has now two

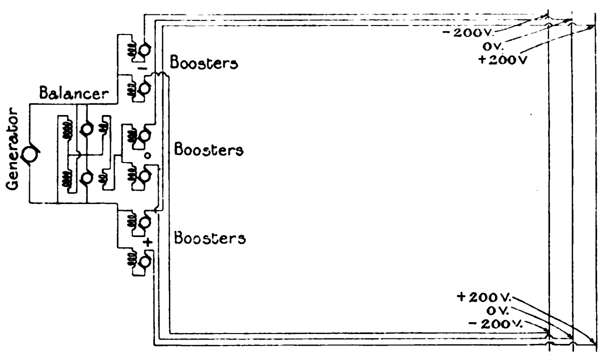

FIG. 8.

paths in parallel by which it may return to the balancer, and, in consequence, the joint resistance of the neutrals will be reduced, and the balancer will over-compensate for the drop, and it must have new coils fitted, or be otherwise altered. Compensating for the drop in the neutral by means of the balancer is, therefore, not completely satis-

factory, as it restricts us to one 3-wire feeder (other feeders being 2-wire) or it entails altering the windings of the balancer itself.

Another plan adopted is to use treble 3-wire boosters, each booster having three generators—one in the positive, one in the negative, and one in the neutral, the latter, of course, being electrically reversible. Fig. 8 shows a 2-feeder system installed on this plan. This is quite satisfactory in work, but it has the disadvantage that each booster consists of four machines, viz., one motor and three generators.

This system, if designed to compensate for the drop in the feeders, is quite stable, and has the advantage that the potentials at the feeding-points are natural potentials, *i.e.*, they are the same amount above and below earth as the busbar potentials. In addition, the load divides between the two boosters in inverse proportion to the resistance of the load from the feeding-points. The booster feeding to the point nearer the bulk of the load therefore takes the greater share of the load.

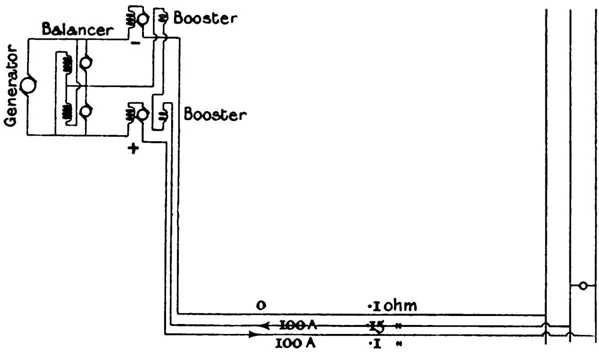

FIG. 9.

Another plan is to use a double booster as before, but with each machine having extra series coils through which the current in the neutral is led. Fig. 9 shows a single feeder fed on this system.

It will be observed that with this type the current in the neutral assists the field coils of the booster on the heavily loaded side, and opposes the field coils on the lightly loaded side. At first sight this would appear to be wrong, and that the booster on the lightly loaded side should be left untouched to obtain correct pressure regulation, but if we consider a concrete case it will be apparent that the lightly loaded booster must also be altered.

Such a booster compensates automatically for all losses, and it may be run in conjunction with one or more similar 3-wire feeders and boosters, but it has certain serious disadvantages.

When the out-of-balance load is much nearer one feeder than the other the booster of that feeder not only takes the whole out-of-balance load, but also relieves the other booster of part of its natural load.

Thus in Fig. 10 we have two boosters of this type supplying a network, and keeping the pressure at the feeding-points at 200/200 volts, similar to the busbars. There is a load of 400 amperes equally distributed over the network and, in addition, a load on the positive side of 80 amperes concentrated at one spot one-tenth of the way along the network from No. 1 feeding-point.

It will be noticed that No. 1 positive booster not only carries its natural load and the whole out-of-balance current, but also relieves No. 2 booster of 16 amperes of its natural load. On the negative side No. 2 booster carries 28 amperes more than No. 1 booster.

The copper is therefore not used to advantage, and the boosters must be larger and therefore more costly than they would be if this effect were prevented.

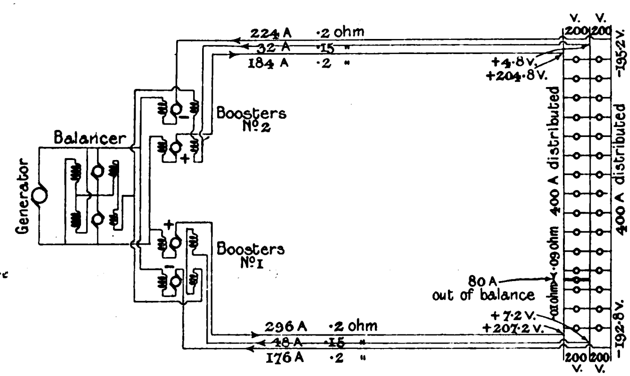

FIG. 10.

Under certain conditions this system of boosting becomes unstable. If we consider that the unbalanced load of 80 amperes is applied at No. 1 feeding-point, and that 60 amperes are evenly distributed along the network, the No. 1 positive booster will supply the whole load of 140 amperes, and No. 2 will supply nothing, as shown in Fig. 11.

If now some of the balanced consumers switch off their lights, No. 1 positive booster will drive a current through the positive of the network and through No. 2 positive booster, reversing No. 2's ordinary boost, increasing the current and leading to disaster, unless reverse-current circuit breakers are fitted.

It will be noticed that the raising or lowering of the potential above earth, at any feeding-point, is caused by the out-of-balance current flowing in the neutral of the feeder, it is therefore not possible to add a common 2-wire feeder and double booster to a system of this kind. All further feeders must be 3-wire, with double boosters having neutral coils. It cannot be said that this system is satisfactory.

Some of these disadvantages are got over by putting the neutral coils of the boosters in parallel, so that the whole out-of-balance

current divides equally between them, but another disadvantage is introduced.

Fig. 12 shows a network supplied by two 3-wire feeders on this system, having nominally 200/200 volts at the feeding-points, carrying

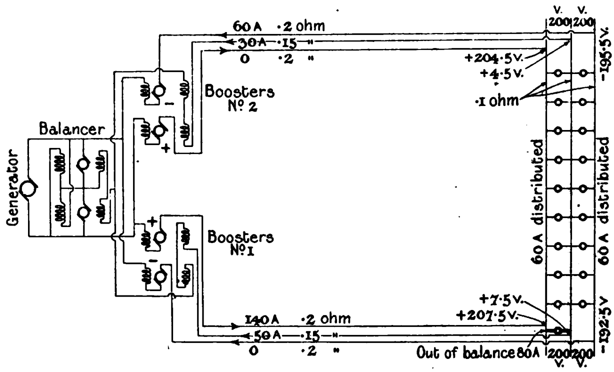

FIG. 11.

400 amperes balanced load distributed equally over the network, and having 80 amperes unbalanced load on the positive side at No. 1 feeding-point. It will be noted that each feeder takes its natural share of the load, that No. 1 positive feeder takes in addition the out-of-

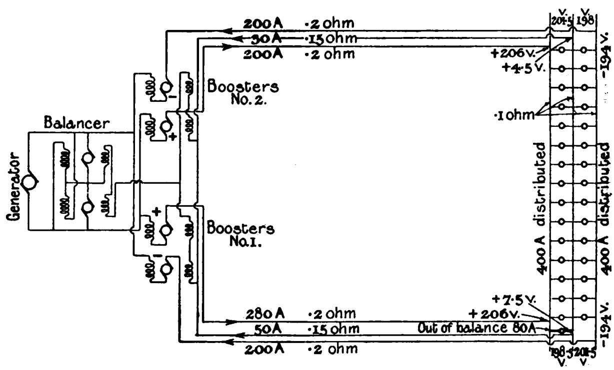

FIG. 12.

balance load, and that the voltage across the outers at the feeding-points is correct. Owing, however, to the neutral coils of No. 1 being excited by less than the current in No. 1's neutral wire, the middle wire at No. 1 feeding-point is not midway in pressure between the outers, but has 3 volts more on the negative side than on the other.

Similarly No. 2 feeding-point has 3 volts more on the positive side than on the negative. This system, however, uses the copper to somewhat better effect than that in Fig. 11.

Another system of 3-wire booster having only two generators is

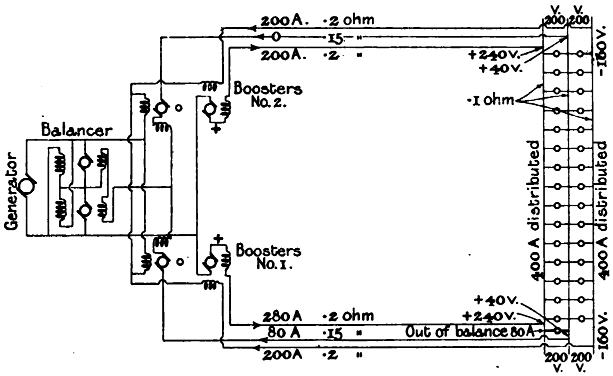

FIG. 13A.

shown in Figs. 13A and 13B. There is one generator in the positive which is excited by two coils, one in the positive feeder and the other in the negative feeder. The positive coil adds the voltage equivalent to the drop in the positive feeder, and the negative coil adds the drop

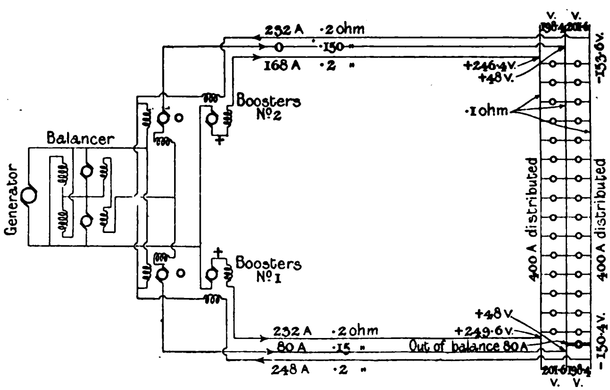

FIG. 13B.

in the negative feeder. The pressure across the outers at the feeding-point is thus always kept at 400 volts.

There is also a generator in the neutral of the feeder, which also has two exciting coils. One of these coils is the neutral coil which adds, or subtracts, the drop in the neutral feeder. The other coil is a negative feeder coil, whose function is to raise the voltage of the

neutral at the feeding-point by the drop in the negative feeder. These negative coils are equalised as shown.

So long as any out-of-balance current is on the positive side, and the other load is equally distributed, the voltage regulation is perfect; but as soon as an out-of-balance occurs on the negative side, or the load centre is not central on the network, that is, as soon as the two negatives carry different currents, the voltage is slightly upset.

Fig. 13B shows the same load distribution as Fig. 13A, but with the out-of-balance on the negative side in place of the positive. It will be noted that this causes the maximum current in any feeder to become 234 amperes, in place of 280 amperes as in Fig. 13A, and it keeps the voltage across the outers correct; but it causes a difference of voltage from the outers to the neutral.

If, to avoid this, the negative coils in the neutral booster are not equalised, circulating currents may occur in the neutral.

Seeing that manufacturers of boosters and balancers do not care to guarantee a much greater degree of accuracy than a voltage error of 5 per cent. from the straight-line voltage for the booster, and an error of 2 per cent. for the balancer, it does not seem wise deliberately to adopt a system which introduces another error of 1 per cent. or so, especially as these errors may be cumulative, and have to be added to the busbar and temperature errors.

All things considered, the system shown in Fig. 8, having three generators, one for each wire, is the most accurate and simple. Its cost is practically the same as that of the boosters with neutral wire coils, as in the one case there are three small generators, in the other case two larger generators with special coils. In one case where the author was quoted alternative prices for the two systems, there was only £10 difference in the cost of the boosters.

An additional advantage is that all future feeders may be ordinary 2-wire feeders having 2-generator boosters, and the whole system remains stable, so long as the boosters do not overcompensate for the drop.

In a large town the best arrangement is probably to have two 3-wire feeders and boosters feeding to fairly widely separated points, equidistant from the load centre of the network, and to make all other feeders 2-wire only. Having two 3-wire boosters, one is always available to feed the balancer in case of a breakdown on one neutral feeder or on one of these boosters.

Having chosen the boosters most suitable for 3-wire feeders, the next step is to decide upon the winding of the balancer. A simple shunt-wound hand-regulated balancer will, of course, meet the case, but its success depends upon the watchfulness of the attendant. A shunt-wound balancer directly excited across the outers is not satisfactory for reasons formerly given, and the balancer should at any rate have the fields crossed as shown in Fig. 5. With this arrangement, if the machines are working on the straight part of the induction curve, a nearly correct balance of voltage is obtained, but the addition of

crossed series coils does not add much to the complication, and ensures greater accuracy of balance of voltage.

The arrangement recommended, therefore, for towns having several feeders feeding the network at some distance from the generating station, is to have two 3-wire feeders and as many 2-wire feeders as may be necessary.

Each 3-wire feeder to have a booster consisting of one motor driving three generators, one in each wire.

Each 2-wire feeder to have a booster consisting of one motor driving two generators, one in each outer.

The motors driving the boosters in each case are better if compound wound, so that a constant speed with any load may be kept on the boosters. With such a boosting system the voltage may be balanced at the station by means of a shunt-wound balancer with field coils cross-connected. The generators should be level compounded, so that the busbar voltage may be kept constant, but they should also have

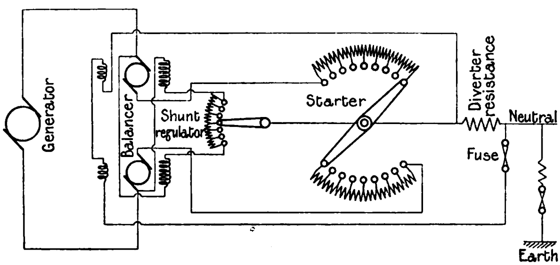

FIG. 14.

some shunt-hand regulation, so that the voltage at the busbars may be raised at times of heavy load in order to raise the voltage at the feeding-points, and so compensate for the drop in the network.

The essence of stability in such a system is that the pressure at the feeding-points shall not be greater than the pressure at the busbars.

The author does not propose to touch upon the switchgear for these machines; but it may be well to point out two precautions which should be taken.

With a motor-driven booster, if the motor should come off the line owing, say, to a broken shunt wire, the booster will be driven as a motor and may rapidly reach a bursting speed. To prevent this danger a circuit breaker may be used, through the jaws of which the booster-current flows, while the actuating coil is in series with the shunt-winding of the motor. If, then, the motor should come off the line the circuit breaker will open and cut the booster out of circuit.

The other danger is in connection with compound-wound balancers, and there has already been pointed out the necessity of using a fuse on the path to the series coils in conjunction with a diverter resistance. Fig. 14 shows one arrangement of balancer with fuse and diverter.

In some towns it may be possible so to arrange the feeders that two or more of them may be boosted by the same booster without introducing any serious error. Such an arrangement deserves consideration.

At times of light load, the group of feeders is supplied direct from the station busbars, and the balancer always deals with the drop in the neutral. It is only when the load has increased to a certain amount that the booster is switched in to the circuit, and it consists of two generators, one positive and one negative, feeding, what one may call high-tension busbars from which the feeders are fed.

On switching in, or out, a booster of the capacity of this one, a decided flicker would show in the lamps, unless special precautions were taken. Fig. 15 shows one method of doing this. It will be noted

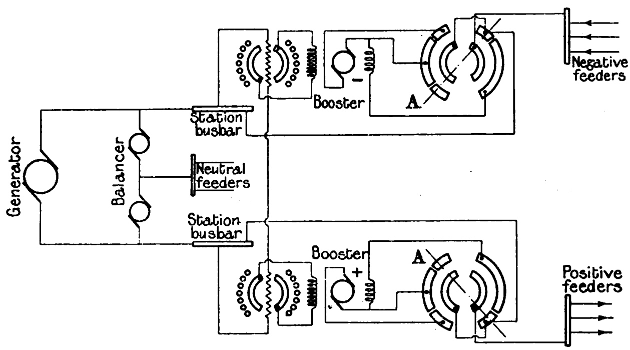

FIG. 15.

that the series boosters are also wound with shunt coils excited across the low-tension busbars with potentiometers in the circuit. By adjusting the potentiometer arm the shunt coils can be made to oppose or to assist the series coils, or to have no excitation. The switches *A* have three contacts, and the method of operation is as follows :—

In the normal position of switch *A* the current from the station busbars passes through the switch to the high-tension busbars without passing through the booster. The booster motor is started up, and switch *A* is moved to the mid position. The current now passes through the series coils of the booster on its way to the high-tension bars, and the booster armature shows a voltage, but there is no path through it. The potentiometer is then adjusted to oppose the series coils, until the voltmeter across the armature shows zero, or preferably a very small voltage. The booster is then switched into the circuit. The potentiometer is then moved back to the zero position, and the whole current then passes through the booster on its way to the high-tension bars, and is boosted in proportion to the load. It is evident that, as the booster is switched in when it has no voltage across it (or

preferably a small voltage, which will just compensate for the drop in the booster armature), when the feeder current passes through it, there cannot be any flicker in the lights.

The potentiometer can be used to compensate for any error in the series coils. There are various circuit breakers and trip coils necessary to ensure safety if the motor should come off the line ; but the author did not think it advisable to complicate Fig. 15 by introducing them.

Some very large boosters of this type have been used. In one case, within the author's knowledge, the booster handles 6,000 amperes.

It does not appear advisable to instal such large boosters and incur the loss in the booster motors and generators, when the station dynamos might have their voltage raised and supply the bars direct.

Fig. 16 shows one method of obtaining this object. The group of feeders are connected to the high-tension busbars, and the station

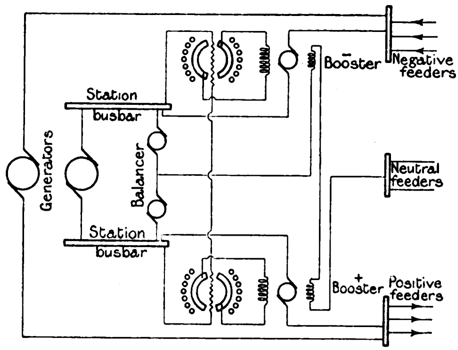

FIG. 16.

dynamos are arranged to be plugged on to either the station busbars or the high-tension bars.

The dynamos are fitted with voltage regulators operated by means of pilot wires from a selected average feeding-point, and thus the voltage on the dynamos and the high-tension busbars is raised automatically as the load increases.

If, now, a link is made between the station busbars and the high-tension busbars, the high-tension dynamos can be kept at full load, the station busbars supplying the remainder of the demand of the feeders, if that is in excess of the dynamo capacity, or receiving the excess from the high-tension dynamo if the demand of the feeders is less. This link takes the form of a booster, having two shunt-wound generators with potentiometer adjustment. If the booster generators are also wound with neutral wire coils, as shown, they compensate for the drop in the neutral, and the station balancer may be a simple one, keeping the voltage of the station end of the neutral midway between the station busbar voltages. This, of course, has several advantages which need not be mentioned.

The following is the method of operation :—

At times of light load the station busbars supply the high-tension bars, and therefore the feeders through the boosters, the latter being regulated by the attendant to keep the voltage at the feeding-point constant. When the load on the feeders exceeds the capacity of the boosters, a generator is run up to the high voltage required and switched on to the high-tension bars. The attendant then reduces the voltage of the booster till the generator is taking its full load and the booster supplying very little. If there is not sufficient demand on the feeders to load the dynamo, the attendant reduces the excitation of the boosters, which then feed the station busbars, and help the other generators supply the low-tension demand, or charge the battery if there is one.

By means of the potentiometers the attendant can compensate for any inaccuracy in the neutral coils of the booster, adding to the voltage of one side, and reducing that of the other, and so keep the balance correct at the feeding-point.

By this plan only small boosters are required, and economy is gained by the saving in the loss in large boosters, and by being able to keep the generator at, or near, its full load all the time. It is, of course, not truly automatic, as the attendant must attend to the adjustment of the booster potentiometers; but any failure to do so on his part merely affects the proportion of the load taken by the booster, and does not affect the voltage at the feeding-point, which is kept correct by the automatic regulator on the dynamo and by the neutral wire coils on the booster.

When several feeders are fed by the same booster, or generator, the drop in each feeder is affected by the position of the load centre on the network, so it is generally in towns having a fairly equal density of demand that this system can be adopted without much variation of pressure at the various feeding-points.

DISCUSSION.

Mr. Lackie.

Mr. W. W. LACKIE (*communicated*): My remarks will be confined to a reference on page 502 with regard to the best arrangement of 3-wire feeders and boosters in a low-tension system. For some years now it has been agreed generally that networks should not be joined up solid throughout, and in Glasgow each feeder is a 3-wire feeder, and further, each feeder supplies an isolated piece of network, radiating usually in eight directions from each feeding-point. Of course, arrangements are made whereby any part of the network can be disconnected from one feeding-point and connected to the adjacent feeding-point. By this means it is possible to allocate the load on different feeders at times of full load, so as to give fairly equal voltages on all the feeding-points. There are other advantages of having each feeder supplying isolated networks, quite apart from the question of balancing the pressure at the feeding-points on the

3-wire system. In large cities arrangements are made so that any generator can be joined up to any one of three or four busbars, and at times of maximum load when boosting is required on single feeders, the generators are divided up amongst these three or four busbars, the voltage of the bars varying by about 10 volts from one another. This state of affairs lasts for three or four hours in a winter afternoon only. Another way of meeting the problem is to have boosters between the different sets of busbars, either motor or steam driven. Energy is transferred from one busbar to another through the booster. Another method used in Liverpool was to insert storage batteries in series with each feeder to raise or to lower the pressure in different feeders. Mr. Lackie.

Mr. S. A. SIMON: Mr. Ker has, I am sure, given us a minute description of all the possible methods of balancing by the use of rotary machinery, but he has not mentioned a very useful piece of apparatus which does not possess some of the disadvantages of a rotary balancer. I refer to the static balancer, which has been in use for many years, and deserves to be better known. A static balancer consists primarily of a choking coil connected between two points of opposite polarity on the armature of a continuous-current generator. As a general rule—it is, as its name implies—separate from the armature, the connections being made through brushes and slip-rings. The middle point of the choking coil is connected with the neutral wire of the 3-wire system; alternating currents flow through the choking coil and keep the voltage of the middle point practically constant. These balancers can be applied both to shunt, and compound-wound machines. Generally speaking, a regulation of 1·5 per cent. with an out-of-balance current of 15 per cent. of the generator output flowing through the middle wire can be obtained, or with 25 per cent. out-of-balance current 2·5 per cent., figures which, I think, will be found perfectly satisfactory in practice. My firm has supplied a large number for the electricity supply station of this city to the Manchester Corporation and in the London district, and they have always given eminent satisfaction. Mr. Simon.

On page 493 Mr. Ker's statement that the voltage of an alternating current to direct-current motor-generator is regulated by altering the speed of the set is evidently due to an oversight. It is now generally acknowledged that rotary converters are more economical and efficient than motor-generators. A very good method of regulating the voltage of rotary converters, is by the addition of a small 3-phase booster connected in series between the secondary of the transformer and the alternating-current side of the converter. By adjusting the field strength of this series generator the 3-phase voltage impressed on the converter and the corresponding continuous-current voltage are regulated to a nicety.

The facility with which any desired range of voltage regulation can be obtained, the exceeding fineness of the regulation, and the simplicity of the regulators which only deal with a small excitation current, are some of the advantages of this system compared with others

Mr. Simon. involving series choking coils with movable cores, or tappings on the transformer with complicated switchgear, which must necessarily be heavy enough to carry the main current.

Mr. J. A. Robertson. Mr. J. A. ROBERTSON: The paper is interesting as showing the different methods of using feeder boosters, but would have been even more serviceable eight or ten years ago. Transmission by 3-phase alternating currents to sub-stations with short low-tension feeders is now the standard practice, and except in very rare instances one would never think of installing feeder boosters to keep constant voltage on the network. The idea of operating boosters at the feeding-points is out of the question, and if it is necessary to meet peak load demands at the end of a long feeder, it would be better to go the whole way at once and instal a battery sub-station with automatic boosters. Mr. Ker seems to strive too much after automatic regulation of voltage, and to obtain this he uses series-wound boosters. If only one booster is required the result may be all right, but I foresee possibilities of trouble where a number of series boosters are working in parallel from the same busbars; in any case, the switchboard attendant should be able to control the voltage at the feeding-points, and it is not desirable to provide him with too many automatic devices. Shunt- or compound-wound boosters appear to be more suitable than series boosters for the ordinary conditions in central station work. It was interesting to hear how Mr. Lackie divides his distributing system into sections, each supplied with its own feeder, the feeders being grouped on separate busbars. This system is all right where one can afford the copper, but even then there must be difficulties about voltage regulation. From the latter point of view the better way is to link up the network through interconnecting fuses, which will automatically disconnect in the event of a heavy short circuit occurring. With regard to balancers, I do not believe in series winding on the balancer field. Difficulties in balancing often arise from the balancer being too small, and it is better to use one large steam balancer than two or three small motor balancers. I have a case in Greenock where 500 H.P. of motors is supplied from the outers and neutral of our ordinary 3-wire system. These motors were wound for 240 volts, and drive cranes, compressors, and planing machines, the largest being 80 H.P. The supply is given from a special feeder, and we have been entirely free from voltage disturbance, the reason being that a steam balancer of 750-k.w. capacity is always in use. The additional loss through driving two machines at 250 volts instead of one machine at 500 volts is not more than would be incurred by motor-driven balancers, and the stability of a large balancer with cross-connected fields working on the straight part of the magnetisation line is a most important advantage. I really think that there are only a few systems where feeder boosters are now employed, and in some of these the difficulties could have been more economically dealt with by a judicious expenditure in feeders or distributing mains. The static balancing described by Mr. Simon is most interesting, but it is a fact, I believe, that this method is only used

Mr. Robertson.

at present with direct-current generators driven by 3-phase induction motors. I believe they have only been used in connection with motor-generators, but it is interesting to know that with the limit of 15 per cent. out-of-balance we can get such fine regulation as $1\frac{1}{2}$ per cent.

Mr. Sayers.

Mr. W. B. SAYERS: What I am going to say may perhaps have some historical interest; I think the first 3-wire boosters were built in Glasgow. In 1895 or 1896 I designed two 3-wire boosters for the Derby electricity supply station of the Midland Railway Company. My brother, Mr. J. Sayers (now telegraph superintendent to that company), had determined that it was necessary to wind the middle wire as well as the outers around the booster magnets in order correctly to maintain a steady voltage on both sides with varying loads and out-of-balance conditions. Each booster consisted of a shunt motor of about 10 B.H.P. coupled direct to two machines, the armature and one pair of field coils of each being in series with one outer, but in addition a second pair of field coils upon each magnet was in series with the middle wire, so that the booster voltage on each side was determined by the sum of the magnetising effects of the outer and middle wire currents, and thus the drop in the middle wire was correctly allowed for, no matter in which direction the current in it flowed. The boosters were built at Messrs. Mavor and Coulson's works at Orr Street, Bridgeton Cross, and were quite successful. Before that boosters were hardly known except in America.

Mr. A. P. Robertson.

Mr. A. P. ROBERTSON: With reference to boosters, I am not very clear whether Mr. Ker would prefer a booster on each feeder. The system in Glasgow is that the feeders are grouped on separate busbars, and there are not usually more than 2 voltages on a winter evening, and if the feeders are properly arranged, this gives the proper voltage at the feeding-points. The voltage has come well within the 4 per cent. variation allowed by the Board of Trade. There are not more than 10 or 15 volts of variation in all the feeders. With regard to balancers I am surprised the static balancer was not mentioned in the paper. The static balancer does not regulate the voltage as a rotary balancer would, that is, it does not boost the heavily loaded side; it rather keeps the voltage on each side of the system very nearly equal. We have a good many static balancers in the Glasgow system, and in many cases there is no motor balancer, and yet the voltage is kept very well balanced. In the case of a large out-of-balance load in the system, it is an advantage to raise the one side at the feeding-point, and in that case a rotary balancer seems to be better.

Mr. Allan.

Mr. P. F. ALLAN: As illustrating some of the problems connected with balancers and boosters, I would like to mention a scheme I had occasion to look into some three or four years ago. Some large works were supplied with direct current at two points from the ordinary town network (3-wire), and at the further of these two points by a direct feeder on the outers only. It was intended to boost up this direct feeder to compensate for the overload on the network. Some time after I had commenced my duties I heard certain complaints that the

Mr. Allan. booster in the generating station was not coming up to its specified work, and that the meters in the sub-station were behaving in a curious manner. Without going into too many details, I would like to say that an extraordinary blunder had been made. The work was equipped with old 240-volt motors, and these had been equally divided between the two sides of the system, and were balanced by several balancers (one in each sub-station) acting on an artificial (or floating) neutral point. The Supply Company's engineer overlooked the fact that by boosting on one outer only—as he had done—he upset the balance of voltage, and consequently fed back through the works network and sub-stations on to the town network. I cannot agree with Mr. Ker that boosters should be used on feeders, except in extraordinary cases.

Mr. Ker. Mr. W. A. KER (*in reply*): As far as Mr. Lackie's criticism is concerned, I do not think it would apply to very large towns like Glasgow, but I agree with him that boosters on all the feeders in such a town would be hopeless, although I think it would be very much more economical if they were all connected up in the usual manner in smaller places. As to the storage system used in Liverpool, I think there will be a good deal of trouble in keeping the storage batteries in good condition, because one feeder may for weeks at a time only require three or four cells discharging into it, and the difficulty in finding the cells which have discharged more than others must be considerable. I think there is one thing in the paper that is novel, due to myself, and that is the system mentioned at the end of the paper. I believe that has never been described before. As to Mr. Simon's reference to static balancers, I believe these only act by their inefficiency; if they were efficient they could not balance at all, and Mr. Simon's estimate of 1½ per cent. seems to me to be rather too good to be true, and it is not good enough for the continuous-current rotary balancers. It is, however, of use where they rough balance, and speaking of Mr. Robertson's disapproval of boosters and preference for hand regulation, I cannot agree with him. Hand regulation is distinctly uncertain, and it is much better to have something automatic. A series booster cannot go wrong, and its inaccuracy is purely that of construction or design. I think series winding distinctly tends to improve regulation. The series booster regulation on the switchboard is not a thoroughly satisfactory arrangement.

METALLIC FILAMENT LAMPS: THEIR POSSIBLE BENEFICIAL EFFECTS ON SUPPLY UNDERTAKINGS.

By G. WILKINSON, Member, and R. McCOURT, Associate Member.

(*Paper received from the* LEEDS LOCAL SECTION, *November* 1, *and read at Leeds on December* 15, 1909.)

The subject of metallic filament lamps has been brought before electrical engineers so prominently within the last two years, both in the technical press and in papers before the Institution of Electrical Engineers, that there is a danger of the subject being now regarded as hackneyed, and an impression conveyed that all has been said that can or need be said in this connection. There is one important aspect of the discussions which have already taken place, however, which is worth noticing, and it is that they have all been in the nature of suggestions and advice as to what should, could, and ought to be done in order that the general public might be brought to realise the immense step in advance over the older types of incandescent lamps, and, more important still, to impress the consumer (both present and prospective) that the last and only objection to the use of electricity—viz., its price—has now been completely met. These papers and the discussions thereon have consisted largely of suggestions how to meet the slump in the demand for electricity for lighting purposes, and it has even been suggested that it would be necessary to increase the price per unit for current used for that purpose.

In this paper it is intended to give some idea of what has been done in Harrogate to counteract the effect which the introduction of metallic filament lamps has produced in a system where the bulk of the demand on the station is for lighting purposes, and where the supply is alternating current, conditions which admittedly favoured the largest possible use of the new lamps in the shortest possible time.

In the first place, the question as to whether the price per unit ought to be increased had to be faced, and it was felt that inasmuch as consumers are naturally chary of introducing new lamps before being fully assured of the reality of the claimed advantage, the anticipated large adoption of them was bound to be gradual, and it was therefore decided not to recommend an increase in the price, but rather to adopt a policy which would educate the public to appreciate the economy and possibilities of the new lamps.

Street Lighting.

It has always been regarded as an axiom in central station circles that good street lighting is one of the best advertisements that an electricity department can have, and by way of experiment a 17-ampere open-type alternating-current arc lamp which had been in use over 12 years was displaced by a 4-arm fitting having four 100-c.p. metallic filament lamps. The general public and the local press, without knowing anything of the saving in current, expressed themselves in no uncertain voice as being in favour of the incandescent lamps, largely because of the absence of the flickering and light variation so characteristic of the arc lamp. When it was further pointed out that not only was there a large saving in current consumed, but that the additional costs of arc lighting—viz., carbons, trimming, repairs, and wages were not necessary in the case of the metallic lamps—instructions were given to convert the greater part of the arc lighting of the town to the newer form of illuminant. It was decided to deal first with a stretch of roadway then lighted by twenty open-type series alternating-current arc lamps, arranged in two circuits and supplied from two floating coil constant-current transformers, and it was arranged that eighteen of these arc lamp-posts should be fitted each with 2-arm fittings carrying two 100-c.p. 200-volt metallic filament lamps, and the remaining two posts fitted with 4-arm fittings carrying four 100-c.p. 200-volt metallic filament lamps. The 100-c.p. lamps are not enclosed, but are exposed to the atmosphere, and this condition has undoubtedly tended to increase the life of the lamps. Each arm is fitted with a 13-in. holophane reflector, which, while giving a pleasing effect in the daytime, materially assists the effective illumination when the lamps are alight. This work was carried out and completed towards the middle of last March, and while the amount of illumination given by two 100-c.p. lamps is by no means equal to that given by the old arc lamps, yet it is admitted that the amount of effective illumination given on the roadway by the 4-arm fittings is at least comparable with that given by the arc lamps, and much better round the base of the post itself. The roadway in which these lamps are fixed is in a residential district, and is now considered to be adequately lighted, the inference being that with the arc lamps it was over-lighted. In the case of a business street it would not be sufficient simply to displace arc lamps by two 100-c.p. metallic filament lamps, but in addition new intermediate posts having similar fittings would have to be erected. As a matter of fact this is the procedure which is being adopted in Harrogate. It is noteworthy at this point to observe that these lamps are being used in parallel on high voltage, and although up to the present moment they have been burning for, say, 1,000 hours, the renewals in that time have only amounted to seven out of 46, and of these seven two were broken by the post on which they were suspended having been run into by a motor van.

Careful photometric tests have been taken in the streets with a

portable photometer, and the results show that the same average illumination is obtained at the following average distances :—

Arc lamp (17 amp. open-type, opaline globe) ...	28¼ ft.
4-light fitting	27½ „
2-light fitting	21½ „

The cost of the alteration of the 20-arc lamps to 2- and 4-arm fittings, including ornamental arms, reflectors, lamps, and all labour, and without any allowance for scrapped material, was £91. This is very low, and is due to the fact that no alteration in the mains was required, as the cables formerly carrying the high-pressure constant current for the series arc lamps were of sufficient cross-sectional area to carry the current at 200 volts for the metallic filament lamps.

The cost of current at 1½d. per unit and maintenance per annum for the arc lamps as compared with the metallic filament lamps is shown below :—

Arc Lamps.	£	s.	d.	*Metallic Lamps.*	£	s.	d.
Current	169	0	0	Current	56	0	0
Trade account ...	22	0	0	Renewals	29	7	4
Wages...	61	0	0	Wages...	6	10	0
	£270	0	0		£91	17	4
				Say	£100	0	0

In this comparison it is estimated that each metallic lamp will be renewed twice per year, which is undoubtedly higher than will occur in actual practice, as the Harrogate lamps are switched out at 12.30 a.m., excepting special corner lamps, so that it is evident that the capital cost of making the alteration is more than met by the saving in the running costs of the first year after the alteration has been made.

In addition to the marked economy which can be obtained in the case of arc lamps by substituting large candle-power metallic filament lamps, it can be proved that the smaller metal lamps may be used as a most effective competitor against the incandescent gas mantle for side-street lighting. From the result of many photometric tests of gas mantles in the roadways, it is proved that the average candle-power of a 3-ft. incandescent gas mantle does not exceed thirty candles, while with metallic filament lamps 30 c.p. can be obtained for 33 watts. Taking the price per unit for street-lighting purposes at 1½d., the price per hour for 30 c.p. is $\frac{50}{1000}$d. ; take the price of gas at 2s. 2½d. per 1,000 cub. ft., the cost of 30 c.p. per hour is $\frac{80}{1000}$d. ; so that for 1,000 hours the cost of electricity is 4s. 2d. against 6s. 8d. for gas, but the renewals in the case of electricity (assuming the life of the lamps to be 1,000 hours) cost 3s., and for gas (assuming the life of the mantles to be 400 hours) cost 10d., making the totals, electricity 7s. 2d., gas 7s. 4d. These figures do not include the extra cost of labour in the renewals of the gas mantles nor the cost of breakages of chimney glasses which

frequently occur, nor extra cost of cleaning the gas lanterns. Since the carbon filament lamps have been displaced by metallic filament lamps in the converted gas lamp-posts, the lighting of all new roads, whether undertaken by the corporation or by private owners, has been given to the electricity department if there was a cable anywhere in the vicinity.

In connection with this point, the special attention of manufacturers of lamps is drawn to the fact that in nearly all street lamps changed over from gas to electricity, the convenient way for the metal lamps to be installed is in a lampholder screwed on the end of a vertical pipe standing up in the centre of the lantern and with the lamp cap downwards. There is therefore a good and immediate market for a lamp in which the leading-in wires are taken to the top of the glass support, and the filament suspended therefrom in exactly the opposite way from what is the standard practice to-day. There is good reason to assume that the life of these lamps would be substantially longer than that of the present lamps when used with the cap downwards.

Private Lighting.

While the lighting authority is making these drastic alterations in street-lighting arrangements the private consumers have not been slow to take advantage of the opportunity afforded them by the metal lamps to reduce their lighting accounts. This effect was noticed first in the business part of the town, where the shops are chiefly supplied at 100 volts. The local contractors for a time found themselves unable to supply the demands for lamps. One good result accruing from the change was in getting a number of installations re-connected which had gone back to gas. The general effect on the supply station, however, from this class of consumer was not so apparent in the reduction of the number of units sold so much as in a generally increased illumination. However, as the average householder began to realise the possibility of installing a small transformer to reduce the supply pressure to 25 or 50 volts, and also that metallic filament lamps of 16 and 25 c.p. at 25 volts were quite as stable and dependable as the old carbon filament lamps, it was found by our monthly generation sheet that instead of, as formerly, having to record with unfailing regularity an increase in the number of units generated, as compared with the similar month in the previous year, the ominous word "decrease" was creeping in.

As an instance of the marvellous results which can be obtained by the use of metallic filament lamps at low voltages, the following figures relating to a large hotel in Harrogate which adopted the method are of interest: In the year ending December, 1906, they used 13,712 units, while in the year ending December, 1908, they increased their illumination and used only 7,672 units. Notwithstanding the possibility of such a remarkable reduction in the number of units used by the larger consumers, and in spite of the fact that approximately 30,000 to 40,000

metal filament lamps have been disposed of in Harrogate, the number of units sold for lighting purposes for the year ending March, 1909, are only 5 per cent. below the figure for the year ending March, 1908, and the figures for units sold for all purposes are only down 2·5 per cent. While it was gratifying to realise that the gloomy prophets who prognosticated that in a short time the output of the majority of electricity supply stations would be so reduced that it would be necessary to increase the price per unit were entirely at fault, it was felt that some steps ought to be taken to use the weapon science had placed in our hands to try to introduce electric lighting into the smaller houses, and thus tap that source of revenue which the gas companies have found so remunerative, viz., the class of house which has seldom more than from 2 to 6 lamps alight at one time. This problem was complicated by the fact that in the past all the details in connection with services are arranged so as to be able to supply at least ten times the capacity of such small installations, and that, unless cheaper services can be installed, the revenue from such consumers would scarcely more than pay the interest on the capital costs.

It was realised that in dealing with small consumers it would be a great advantage to have no meters, and to charge them for their supply on a contract system. The great disadvantage to such a system, as proved by previous experience, was that unlimited use of the supply was apt to be taken unfair advantage of, and in view of that it was decided to offer a contract system of charging on the following terms :—

I. Consumer must supply his own lamps.
II. Each apartment in which a lamp was installed must be adequately lighted by windows in the daytime.
III. The maximum number of lamps to be alight at one time to be declared at the commencement of the contract.
IV. The minimum number of lamps applied for to be 2 and the maximum 6, each taking 30 watts.
V. The charge to be 2s. 9d. per quarter per 30-watt lamp, payable in advance.

Clause I. tends to counteract the temptation to use the light more than actually necessary because of the cost of renewals of these comparatively expensive lamps.

Clause III. enables the department to instal a current limiter which causes the lamps to flicker if more than the number contracted for are switched on.

For the purposes of comparison with the contract rate of 2s. 9d. per 30-watt lamp, the accounts of a number of representative consumers who are charged on the maximum demand indicator system were taken and worked out on this basis, and it was found that the average from these consumers in terms of 30-watt lamps was nearly 50 per cent. below this contract rate, so that a safe margin is left to balance the

more free use of the supply which it is only natural to expect would take place.

The current limit indicator which has been adopted is of a simple thermal type, compensated for variation in atmospheric temperature, and is made by a well-known firm of instrument makers in London. The cost is less than half the price of a reliable meter.

The advantages of the contract method of charging for a supply of electricity on these lines are so obvious that it seems scarcely necessary to enumerate them, but it is interesting to note that they are almost equally as attractive to the consumer as to the supply authority.

They are as follows:—

1. Consumer knows exactly what the amount of his quarterly account will be. This is a strong point.
2. Consumer can have the use of the light in every apartment. This is a boon to him, particularly in the case of bedrooms, as it is found under the old *régime;* in the smaller houses the tendency is not to use electric light in these rooms.
3. The supply authority is saved the cost of demand indicators, half the cost of the meters, and the continuous expense of repairs and recalibrations and the excitation current taken by the meters, also the cost of meter readings.
4. The book-keeping is simplified, and the risk of incurring bad debts is banished, due to the payment being made in advance, a feature of some importance where tenants are on weekly tenancy and where "moonlight flits" are not unknown.

It has been found that, if builders are induced to wire their houses, the tenants are extremely anxious to avail themselves of the use of electricity; and on one new building estate, where 100 to 120 houses are being erected of the value of £20 per year or less, an agreement to supply on the contract tariff has been entered into, while the builder has agreed to wire the whole of the houses as they are built.

COST OF SERVICES.

Reference has already been made to the very serious difficulty which had to be faced due to the fact that the requirements of these installations did not necessitate anything like the same expenditure on services as had been customary. Further, the more stringent regulations of the Local Government Board, in regard to the repayment of loans, have made it essential that at least 8 to 10 per cent. should be set aside each year out of the profits of the department to meet interest, sinking fund, and depreciation charges, and thus made it impossible to make a satisfactory profit on these small consumers unless the cost of services could be very materially reduced. For example, it was found that the average cost of service and the accessories, including meters, in Harrogate for the four years ending March, 1908, was nearly £7. The

interest on this sum at 10 per cent. is 14s., and if the service to a small house paying 22s. per year for 2 lamps was to cost that sum, there would only be left 8s. to pay for the current consumed. Under these circumstances it was necessary to consider in what direction a reduction could be made. First of all in the matter of cable, our standard practice in services was to use 7/16 concentric paper insulated lead covered and armoured cable, costing about £160 per mile, and it was decided that a 5-ampere cable would be of ample capacity to serve the smaller houses, costing £50 per mile. Then the cut-out box of 25-ampere size, costing 10s. to 12s., was displaced by a smaller box costing 4s. each. Again, the current limiter only costs 15s., as compared with the former price of 35s. to 40s. for a meter. Further, the cost of labour is reduced to one-half of what it formerly was, and it is conclusively proved that the cost of all these does not exceed 45s. to 50s. Having thus reduced the cost of services, it was felt that a most important difficulty had been overcome.

While on this point it is impossible to refrain from referring in the strongest possible terms to the unenterprising attitude of the cable manufacturers to our request for a cheaper service cable. Naturally it was desired that, for the sake of uniformity and facility in testing for and locating faults, the concentric type of cable should be retained, and quotations for sizes down to 7/22 were asked for. The manufacturers pointed out the difficulty of construction of cables of sizes below 7/18, so another inquiry was sent out specifying 7/22 inner, and an outer of equivalent cross-sectional area to 7/18. To our great surprise, the quoted prices for this class of cable were considerably in excess of that asked for our standard 7/16 service cable, and a protest brought the reply that specially to manufacture cables of this description, considerable expense is involved in addition to the ordinary cost, due to the machines having to be prepared specially for irregular sizes of material. Again, inquiries were sent out, this time for 7/22 inner, and the outer to be of either iron or aluminium wires of equivalent carrying capacity to the inner conductor; but the result was still more surprising, as the price asked for this cable was in excess of the price quoted for the standard 7/16, and it was only after a lot of correspondence and several interviews that the special concentric cable which is now in use was evolved by a well known and somewhat more enterprising firm at the price of £50 per mile. (There is a sample of this cable on the table.) It is extremely disappointing at a time when central station engineers are doing all they can to reduce the cost of services and house-wiring to find the cable manufacturers take up such a conservative and unenterprising position in regard to this most important matter.

Electrical cooking and heating are aspects of the question which are receiving considerable attention in many quarters, but as they do not fall within the scope of this paper, it is not intended to refer to them at any length, other than to draw attention to the significance which may be attached to the fact that a great number of patents are being taken

out for apparatus of this description, and no doubt considerable developments may be expected shortly.

It has been found that our efforts to popularise the metallic filament lamp, while they undoubtedly tend to decrease the amount of energy used by the old consumers, have enabled us to win over additional consumers, and we lately have frequently the satisfaction of seeing our monthly generation sheets showing the cheery word "increase" as compared with the previous year. It is because we have arrived at this stage that we have been induced to write this paper.

DISCUSSION.

Mr. Churton.

Mr. T. HARDING CHURTON: Electric lighting was placed upon a practical basis by the introduction of the carbon filament lamp, which superseded a metal (platinum) filament lamp, yet developments perhaps as great are now again taking place in consequence of the reversion to a metal filament, though, of course, not of platinum. The great saving in cost of lighting effected by the new form of lamp must undoubtedly be to the ultimate advantage of every one concerned, though the consequent diminution of output—if in most cases only temporary—must, for the time being, be detrimental to the supply stations. It is satisfactory to hear that the falling off in output from this cause is already being overtaken in consequence of the increase in the number of lamps installed. The advent of the metal filament lamp stands in the same relation to electric lighting as the incandescent gas mantle does to gas lighting, and bids fair to have an equally important effect upon the industry. I believe that the gas companies have found the prepayment slot-meter system popular with small users, and I should be glad if the authors would inform us whether this system might not advantageously be applied to electric lighting for this class of consumer. With regard to the fixed-rental-per-lamp system of charging, while this may possibly effect some saving as compared with the meter system in standing charges, it does not appear altogether an ideal arrangement. As regards the possible abuse of the system, in the first place, not many people would wilfully waste their lamps (especially the more expensive metal filament lamps) as well as the current; and, secondly, even if they did so, it would not matter to the supply undertaking. I believe that the actual cost of generating is somewhere in the neighbourhood of one-tenth of the total cost of production and distribution, and if, therefore, some consumers are wasteful, it would not be likely to have any serious consequence. A matter in connection with the popularising of electric light that demands the attention of supply station engineers is the cheapening of wiring for small houses—cheapening by modifications in methods, of course, not by the lowering of the standard of quality.

Mr. Cridge.

Mr. A. J. CRIDGE: This subject is by no means exhausted, especially when, as we have seen frequently of late, the mention of the wire lamp entrains the question of the method of charging for the supply, par-

ticularly in the case of the small consumer. I am glad that most engineers have seen, as the authors have seen, the inadvisability of raising the price per unit at the present time in order to recover some of the revenue lost by the adoption of wire lamps. The price should not be raised except as a last resource, and to raise it now would be suicidal. To increase the price to users of wire lamps only is also, in my view, illegal. Mr. Wilkinson's street arcs, which have been replaced by wire lamps, seem to have been of an obsolete type, and the comparison given would have been more valuable if it had been against modern flame arc lamps. In the matter of the cost I would protest as strongly as possible against the suggestion that gas at 2s. 2½d. per 1,000 cub. ft. is equivalent to electricity at 1½d. per unit. Gas in Sheffield is 1s. 4d. per 1,000 cub. ft. for private lighting, and is probably much less for street lighting. What chance would electricity have if the comparison were true generally? When I was in Brighton we had a rule that if the electric mains approached within 30 ft. of a gas lamp, it was a case of "Off with its head," and the lamp was converted. Probably the special lamp mentioned by the authors would be very costly, and would have too restricted a sale to tempt the manufacturers to take it up. With regard to private lighting, we found in Sheffield, as Mr. Wilkinson has done in Harrogate, that we recovered many of our old consumers who had gone over to gas. Shops and public-houses of not quite the first rank formed the majority of these cases. We have not encouraged consumers to reduce their pressure below 100 volts. It is, for reasons of current density, a mistake to go even as low as 50 volts on existing wiring, and if, in highly priced places, such as London, it is necessary to be scrupulously economical, new 50-volt installations should be carefully laid down, and all wires should be ample in size. 25 volts is, in my opinion, unnecessarily low, and the cases must be few in which such a low pressure serves any good purpose. With an auto-transformer and balanced circuits, the wiring is very much cut up and complicated, increasing the cost. If a pure transformer is used, I have often found, in my own experience, that the magnetising watts, at 4d. per unit, may cost the consumer £4 or £5 a year. As to contract rates, it is very much open to question whether they are ever justified. But I will say that I think it highly unwise to go in for much formality, or red tape, or limitation of any kind. Let it always be remembered that rules are made for the exception. Mr. Wilkinson fixes a maximum of six lights. Would he refuse an application for seven? I should not be inclined to trust a consumer to turn out his lamps when they were not needed. The check devised in Clause 1—viz., the cost of renewals—would not help at all. At low voltages the life of the wire lamp is to be measured in thousands of hours, so that they might be left on all the year round without great expense in renewals. I would ask if this method of charge is optional or compulsory? The authors speak of doing away with demand indicators; we do not use them. They also refer to doing away with meters, thus saving the shunt losses. In our case the units consumed in

Mr. Cridge.

Mr. Cridge. meter shunts are about 1 per cent. of our total sales, and their cost to the department is less than 0·067 per cent. of the total revenue, so that I do not attach much importance to the item. If all the meters were modern these figures would be reduced by two-thirds. We have not found that tenants always use electric light when the landlord wires the house. Referring to service costs, I thought Mr. Wilkinson was doing better than £7. Our figure is down to £4 now, and it may be further reduced shortly. I think the right system of charging in the case of private houses is not a flat rate with no meter, but a fixed sum per annum, together with a small price per unit.

The fixed charge must *not* be based upon the installation, because this practice tends to prevent the fixing of lamps in bedrooms and bathrooms and other places where the light is not seen much. We want to have electric light everywhere. The price per unit should be of the order of 1d.; then kettles, irons, and stoves could all be attached to the lighting circuit. Here we have a reason for not reducing the pressure too far, for a 50-volt iron takes 10 amperes. The system in vogue at Norwich due to Mr. F. M. Long commends itself to me. The fixed charge is based upon the rateable value of the house. We pay for water on this basis; why should not the preparation cost of electricity supply be paid for on the same lines? I am not surprised that the estimated cost of Mr. Wilkinson's special cable was high. When one asks for non-standard things one must expect to pay a non-standard price. The use of an iron outer conductor for a concentric cable on an alternating supply strikes me as risky. I cannot agree with the authors that heating and cooking are outside the scope of the paper. The subject should be treated on broad lines.

Mr. Schofield. Mr. S. D. SCHOFIELD: Metallic filament lamps are used on the circuits of every supply station with the effect of diminishing the income, and almost every station engineer can see the decrease in the number of units sold and has therefore to look round for some other outlet to make up this deficiency. With reference to the authors' remarks on street lighting, I should like to ask them what was the candle-power of the 17-ampere arc lamps mentioned. The metallic filament lamp has an efficiency of 1·1 watt per candle. If the authors are obtaining as good a light for 200 watts now as from the 17-ampere arc lamps the efficiency of the arc lamp has been very low indeed. It would also be interesting to know the relative heights of the lamps above the ground. I must congratulate them on obtaining street lighting so easily. I find that where gas mains are laid, even with gas at 3s. per 1,000 ft., although we can offer them a superior light at less cost, it is not always easy to get the street lighting. I would also ask the authors whether they find a flexible suspension increases the life of these lamps. In some towns where they have heavy street traffic, particularly heavy electric cars, the vibration in the street has a disastrous effect on the filament of the lamp, and I should like to know if the authors have had any experience of this. No doubt their method

Mr. Schofield.

of charging has answered very well in Harrogate, but the drawback to it is that it takes no account of heating and cooking apparatus. Manufacturers are producing cheaper and better apparatus now than formerly, and with the present low rates of current for this purpose there is a large field open for the supply engineer to get them connected to the mains. Within the last week a consumer of mine took out for himself the cost of an electric radiator and a gas radiator and decided to instal two electric radiators and one kettle simply on the fact that he got much better results at a reasonable rate. The greatest drawback to electric cooking apparatus at present is the duplicate wiring required. In many cases consumers would put radiators in if it was not for the cost of taking the duplicate set of wires back to the meters, and for that reason the telephone method of charging, or the Norwich system, whereby in one case the fixed charges are proportional to the kilowatts taken and in the other case are proportionate to the assessment, with a very low price per unit, is superior to Mr. Wilkinson's method. We must find some load to level up the decreased consumption due to the metallic lamps, and it is only by heating and cooking and power that we can get this result. I prefer the Norwich system of charging, in that there is no temptation to keep the electric light out of the cellars and upstairs rooms.

Mr. Campion.

Mr. R. H. Campion: I should like to discuss this paper from the station engineer's point of view. In a residential district with the load going down new sources of revenue must be found to make up the deficiency in the lighting. The cost of the services to my mind is fairly large. Perhaps the authors can tell us the average number of yards' run for some of the large houses, which bring up the cost considerably. I find difficulty in getting from one house even to the adjoining one. The occupiers strongly object to a hole being knocked through the wall. In some cases I have obtained written permission, which has afterwards been withdrawn, and I have been compelled to take the service out again.

Another point we have to consider is that holophane shades get very dirty, especially in industrial towns, and this reduces the light. I do not think Harrogate has been altogether free from fog since building operations were extended. I certainly think the authors are to be commended for trying to bring down the cost of cables. As Mr. Cridge remarked, the smallest departure from standard size involves extra cost, so that if anything can be done to reduce the cost of cable it is a step in the right direction. We are not sure what size of cables we shall want. If the heating load develops, as we hope it will, we shall require a larger size. My experience with the lighting of cottages has not been very successful. I have obtained a few, and induced the landlord to charge his tenants 1s. per week. They certainly did not keep on long; but the lamps they burnt were of such a description that we were not sorry when they went off the circuit. These people would not replace a lamp costing 9d., no matter what condition it was in, so I am afraid the extra cost of metallic lamps will deter them still further. I cannot

Mr. Campion. help thinking that a great many of the old customers will rush at this no-meter scheme, and the authors will have a hard fight unless they have their committee well under control. They may have to give concessions against their better judgment. The Harrogate system is not new. The Northern Counties Supply Company tried it ten years ago, and had disastrous results with it. Although they had reckoned on a man only having his light on a certain length of time, they found that the colliers never switched it off on principle, because it cost them no more. The authors have, I think, done wrong in reducing the voltage. All heating apparatus makers agree that their radiators cannot be made to operate successfully at less than 100 volts. I do not think these small consumers will put in therol heaters, electric irons, etc., whatever the voltage employed. I do not know whether the Harrogate Corporation possess any powers to let out apparatus on sale or hire terms; but if not, it will be very difficult indeed for any but people with large incomes to employ these contrivances.

Referring to Mr. Schofield's remarks about duplicate wiring, we have adopted a scheme whereby a man can take power for heating apparatus at the ordinary power rates off his lighting circuit, and we charge him a very small rental for his meter. The system has been in vogue a year, but I have obtained only about half a dozen consumers in this way, after circularising all the consumers three or four times. It is the cost of installing that is keeping the people back. The gas people are "in" with gas cookers and radiators, and it is very difficult to displace a thing when once in. We tell them about the obnoxious fumes; but they will not pay for the alterations to be made. The Norwich system, as mentioned by a number of speakers, is extremely difficult to work in certain towns. I know that it has been successful at Norwich; but I presume that it is amongst a good deal of fairly evenly rated property. It applies well to property in the centre of the town which is highly rated; but with a small house some way out there are difficulties in many cases. The inspection of the premises, in order to ascertain what lamps consumers are burning, will be a rather heavy task, and will take longer than the ordinary meter reading.

Mr. Dickinson. Mr. H. Dickinson: I am very pleased indeed that the consumption at the authors' generating station is going up. I have been seriously looking for an increase in our output since 1907, and I think I now see signs of a turn for the better. I have made out a curve showing the additions of lamps and deductions due to changes from carbon lamps to metallic filament lamps, which shows that from the end of 1907 to September, 1909, there has been a total reduction, but the last three months have shown a net increase. Metallic filament lamps have been extensively adopted in Leeds, and I believe they will ultimately prove a great benefit to the supply undertaking. I should have thought that if the use of metallic filament lamps was as great in proportion at Harrogate as it is in Leeds, the reduction of units would have been greater than 5 per cent. With regard to the new system of charging, I think it would be interesting to know how many lamps are connected

up on the new system. I take it that the type of house catered for is about £20 per annum rental. We have already connected 700 or 800 houses of this type in Leeds, and the only advantage I can see in the scheme is that the consumer knows exactly what he is going to pay. Unless he receives some material advantage by this new scheme, I cannot see that it is better than charging the consumer through a meter in the usual way. With regard to the small houses, I think that if the mains are available, the builders prefer to have their property installed with electric light instead of gas. As regards the connections, I should be glad if the author could give us the details of the 45s. and 50s. connections that he mentions. I have been trying to analyse the cost, but I cannot think an individual service would be so low as the figure he gives; he might say whether this price is for connecting new property, or whether it is for connecting an ordinary service in any part of the town. If the services are put in when the cables are laid they work out much cheaper. In Leeds we have many consumers who do not like the supply to be cut off during the day, and we are thus forced to make joints during the night and on Sundays, which adds to the cost of connections. With regard to the sample of cables costing about £50 per mile, this does not appear to be sufficiently mechanical. We have had considerable difficulty with telephone cable not quite so compact in construction but of larger diameter, the trouble being due to the substance of the ground, so that we now have to use the same cable armoured. If the new type of cable is to be laid in iron pipe, this also adds to the cost. Mr. Dickinson.

Mr. J. W. Hame: I think the metallic filament lamp has infused new life into the central station engineer, and also into the contractor. One of the great difficulties, we must confess, is to instal the electric lighting among the poorer classes. The difficulty of supplying new houses is that the bulk of these houses have been erected just outside the limits of the area of supply, and at the present time stations are prohibited from supplying these districts. The builders have no alternative but gas, and when they would have electric light they are barred. When the borough extends its boundaries, gas has already been installed, and people would not wire their houses at their own expense. This is a difficulty which I hope the clause in the Act which has now gone through will help us to get over. The question of the method of charging is a point that is exercising my mind a great deal. I have tried contract demand, maximum demand, flat rate, and other systems, and I am gradually coming to a definite conclusion that whatever is ultimately decided upon it is bound to be some method in which measurement of the units as well as the demand is made. Mr. Hame.

One thing that puzzles me greatly is how central station engineers are able to ascertain the number of lamps connected, and to keep the figures up to date. I keep a record of the additions made each month, but I question the value of that figure as indicating the lamps connected.

One very important item is the cost of putting in services, and it is

Mr. Hame. very interesting to know that a service can be put in for £4. I cannot get below £5, but it depends upon what reinstatement of ground surface has to be done, and it would be interesting to know how much different towns are paying for reinstating over mains and services.

Mr. Fawcett. Mr. I. F. FAWCETT: I am at present a resident in Harrogate, but have not seen the road which contained the arc lamps said to have been replaced. I have, however, seen some streets in the new district, where the lamps are about 100 c.p., and compare very favourably indeed with gas lamps, giving apparently a much wider area of illumination. I cannot agree with Mr. Wilkinson's method of arriving at the cost of lighting by adding 50 per cent. to every consumer's bill on the contract system. As regards the adoption of a limiter, I had not seen inside one of these instruments before to-day, and the action appears to me to be too sudden. I think that this system of lighting will never be really popular until something with a slower action than that of the limiter has been discovered. If it worked only in three or four minutes it might be useful, but the present type is so inconvenient as to render it useless. For that reason I would propose installing a demand indicator, and leaving the consumers to act as their own limiters. With regard to obtaining a lighting load, one reason why the gas companies get the load is because they work for it. They go out to find customers and do all they can to assist them. I am of the opinion that station engineers do not pay sufficient attention to the builder. I am acquainted with a number of builders and they all say the same, that the gas companies are continually worrying them until gas pipes are put in. In considering the question of service wiring and its possible reduction there are two points to consider, the consumers' view and the builders' view, and the cost of the wiring is quite likely to prevent the small houses coming on. The heating question is a point well worth considering, and I have noticed that one or two of the larger stations have a fair number of these consumers on their mains.

Mr. Wilkinson. Mr. G. WILKINSON (*in reply*): I should like to say that Messrs. Handcock and Dykes, who recently gave a paper on a similar subject in London, write as follows: "You will be interested to hear that we have started our Fixed Price Light Company here. We are wiring the poorest houses, and making a charge of 3d. per lamp per week to cover the unlimited use of the light. The wiring is concentric, carried out in Stannos wire, and the cost, including fittings, but exclusive of lamps, is just under 8s. per point, including the main fuse." Surface wiring at 8s. per light, including everything except lamps, is about as low a price as I have come across. We find the cost of wiring to be 9s. per point as a minimum, then there is a charge of 5s. for the metallic filament lamp, pendant, and shade, making a total of 14s. per light complete, ready for use. I have here samples of the service cable we are using. This is not German make, but is made by one of the best cable firms in this country, and whilst I agree with Mr. Dickinson that it is somewhat delicate, yet if laid in iron pipes, and not subjected to strain, it is a reliable main. The iron tube is used with long sockets, which secures

Mr. Wilkinson.

a rigid conduit. To check a number of contract customers we inserted a meter and demand indicator on the supply main, and from readings taken over several weeks, we conclude that the average price per unit obtained will be 3d. over the whole year. Mr. Churton advocated prepayment meters, and thought they would be better than the contract system. A subsequent speaker condemned them, and I quite agree that their cost is heavy and that they are troublesome to maintain. They soon become full of coppers if a large amount of light is used, and it is necessary to send some one to remove the coins, otherwise the meter becomes jammed and the supply stops, or, worse still, the users obtain further supply free. Mr. Churton also referred to standing charges, and mentioned that nine-tenths of the total costs were standing charges and one-tenth running charges, but that is not quite the proportion in Harrogate. If we by a contract tariff get the standing charges secured the running charge is very small indeed, and the margin allowed for running charge is sufficient to prevent loss even with an excessive use, averaging 8 hours per day. We make a reasonable profit; we make no bad debts, as the money is paid in advance. Mr. Cridge suggested that flame arc lamps for streets would be more satisfactory. I quite agree that the use of flame arcs is good practice in the business part of a town like Sheffield, where the traffic is dense and it is worth while to have a superabundance of light, but not in a residential town like Harrogate, where the vehicular and pedestrian traffic is comparatively small and metallic filament lamps give good results. Although they do not give such a cheerful effect they throw a good light on the road surface, as is proved by the photometric tests given in the paper. It has been asked if six lamps is the final contract maximum. I do not think it is, but it is the maximum at present. We are pioneering this contract system, and felt that it would not be wise to embark on a larger scale without further experience. Whatever tariff is adopted, be it contract or otherwise, it is advisable to go slowly so as to make sure of the ground. I was very pleased to hear that in Sheffield they get down the cost of services to £4. It will be interesting to know if this includes reinstating the pavements. I very much doubt if £4 will cover all the outlay. It was mentioned that the contract system might interfere with the wiring of the bedrooms and other apartments. This is not so; it does not matter how many lamps are wired so long as the number of lamps on at the same time does not exceed that contracted for. I cannot see how we are going to get heating and cooking in small houses where there is competition with gas. With regard to the 17-ampere arc lamps referred to by Mr. Schofield, I may say the efficiency was not good, as the lamps are old. These arc lamps take from 600 to 700 watts, and although there was a cheerful effect round about, the light on the roadway was very disappointing. The lamps were placed 20 ft. high, and the metal filament lamps which displaced them 2 ft. lower. In reply to Mr. Schofield, we have had no experience with flexible suspensions. I am sorry we have not had sufficient experience with

Mr. Wilkinson.

the method of putting these lamps into the converted gas lamp upside down to say what effect it is likely to have on the life of the lamp. We find that the lamps last fairly well, but we are in doubt as to whether the breakages are due to the lamps being upside down or, in a number of cases, to the lamp-cleaners being careless and breaking them. Personally I prefer metal lamps put up without lanterns, and they are then free from damage from lantern cleaning. In reply to Mr. Dickinson, I may say that the 50s. for service cable, etc., includes everything, as each service serves as a minimum two semi-detached houses, and the cost of the service is spread over two houses.

I agree with Mr. Campion that the middle classes will not buy therol heaters when they can get gas at 2s. 6d. per 1,000 cub. ft. I am glad to know that Mr. Dickinson's figures are improving. I think it will not be long before there will be still greater improvement in the output, due to the increase of lighting with metallic filament lamps. The Harrogate output is not at present increasing; there was, however, an increase this summer in July, August, and September over the corresponding quarter of last year, but the output for the seven months ending September was 2½ per cent. down. I cordially agree with Mr. Hame that we, as municipal engineers, are not in the business simply to make a profit for the relief of rates, nor to supply the richer ratepayers of the locality. I think it is our duty to endeavour, as far as we can, to bring the advantages of electric lighting within the reach of every ratepayer in the town.

Mr. McCourt.

Mr. R. McCourt (*in reply*): Mr. Wilkinson has replied to most of the points raised in the discussion, still there are one or two matters of interest that I would like to mention. With reference to the consumers supplied on the contract tariff, we lately fixed a demand indicator on a main which serves a large number of them, and we found from the reading of that instrument, compared with their possible maximum demand, that the diversity factor of this class of consumer was as high as 1·8. This result rather surprised us, as we fully expected these consumers would as a rule use all their lamps every night, but they evidently do not. The question of flame arc lighting has been raised. We certainly should have preferred to keep our street lighting in the business part of the town on this system, but the Street Lighting Committee decided otherwise. We have had one of the latest type of flame arc lamps taking 350 to 400 watts fixed on a standard lamp pillar, and our photometer test gave us the same average illumination as referred to in page 511 at a distance of 41 ft. As Mr. Wilkinson stated, we do not recommend 25-volt installations, and the instance referred to in the paper was given as an evidence of what saving can be effected by the adoption of such measures. The manager of the hotel had 25-volt transformers fixed on each floor of the building, and had changed all the basement lighting from gas to electricity. The total number of units used for the year ending December, 1909, was only 6,455 as compared with the figure given in the paper for the year ending December, 1906—viz., 13,712 units, a reduction of 53 per cent. —while considerably increasing the amount of light obtained.

THE IMPORTANCE OF ATTENTION TO DETAIL.

By J. H. RIDER, Member.

(*Address to the* STUDENTS' SECTION, *delivered November* 17, 1909.)

When called upon to write an address for a meeting such as this, an attempt is usually made to find a subject which shall be new, with the intentions of avoiding those which have become hackneyed and of showing originality.

I have, however, chosen as the title of my address to you this evening, "The Importance of Attention to Detail," a subject which, while very old, should be kept in the forefront by every engineer. The tendency of modern living is to take things at a rush and to aim for general effects, rather than to give that close thought and attention to detail which is absolutely necessary if real success is to be attained. We all remember the story told of Michael Angelo. One day a friend visited his studio, and seeing the sculptor at work, said, "You do not appear to have done anything to that statue since I was here last." "Oh, yes," said Angelo, "I have smoothed this elbow, I have touched up this eyebrow, and I have brought out this muscle a little more." "But," said the friend, "those are only trifles." "Yes," replied the sculptor, "they are only trifles, it is true, but trifles make perfection, and perfection is no trifle."

What is true in the world of art is equally true in the world of engineering, but there is no comparison between the relative importance of the results in the two instances. A painting or a piece of sculpture may be more or less beautiful, and only its own intrinsic value is affected. The world cannot really be said to be either richer or poorer on that account. When we have to deal, however, with things which affect the welfare of mankind, attention to detail frequently means all the difference, not only between success and failure, from a monetary point of view, but also between safety on the one side and danger on the other. The difference between the two—and it is a great difference in result—may be controlled entirely by some small and comparatively insignificant detail.

It is not difficult to understand how—

For want of a nail the shoe was lost,
For want of a shoe the horse was lost,
For want of a horse the rider was lost,
For want of a rider the battle was lost,
For want of a battle the kingdom was lost,
And all for the want of a horseshoe nail.

Between the two extremes illustrated by the examples of attention to small things which I have given, in the one case affecting the artistic or monetary value of an article, and in the other affecting the safety of a kingdom, there lies a large field in which the engineer has to work. It is not improbable that the safety even of the kingdom may some day depend upon the attention given to detail by the electrical engineering sections of our navy and army, but we may consider the matter more generally rather from the civil than from the military engineering standpoint.

Engineers may be divided into three classes: those who design, those who construct, and those who operate. While attention to detail is necessary with each class it is of much greater importance in those who design and construct than in those who only operate. A wrongly designed or badly manufactured piece of machinery can never be made to operate entirely satisfactorily, however much care the operator may bestow upon it; but a well-designed machine, plant, or system starts with everything in its favour, and if the manufacturer carries out the good design with careful and sound workmanship, the successful operation becomes a very simple matter.

The importance of attention to detail is, therefore, first emphasised in the case of the designer, but it is impossible to be a good designer without an intimate knowledge of the limitations of the manufacturer and of the conditions under which the machine or apparatus has to be operated. It is my opinion, based upon many years of practical experience, that nearly all the trouble which arises with plant in electric generating stations, which can be traced to causes other than inattention on the part of the operator, is due to the fact that the designers are good draughtsmen and very little else.

To take an instance. A firm decides to place a new line of motors, generators, or turbines upon the market, and the working drawings are prepared in the drawing office. The machine has characteristics which ensure it a ready sale at the start, and numbers of various sizes are put in hand in the shops. By and by there come news of trouble from purchasers. The oiling arrangements are faulty and allow oil to leak about. The bearings tend to run hot unless great care and watchfulness are exercised. The brushes require careful nursing to be made to run sparklessly or without spoiling the commutator. This, that, and the other small, but extremely annoying, accident occurs, and men have to be sent out at great expense to put the matter right. But, by this time, the designs are all finished and it is too late to alter a great deal of the work then in the shops. The designer's only experience of the trouble comes from the reports of the fitters or engineers who have to put it right, and he has not got to suffer, like the operating engineer or the purchaser, from the consequential damages of the breakdown. In other words, his appreciation of the principle that attention to detail is absolutely necessary is modified by the fact that he does not come into actual daily personal contact with the results of his own mistakes and shortcomings.

It would be an excellent thing if every designer were to spend three months in every year in responsible charge of the erection and running of the plant which he designs. He would then learn how attention to apparent trifles makes all the difference in the world between smooth successful operation and continual trouble. Such an arrangement would probably be somewhat difficult in practice, but it is eminently desirable, and would, I am sure, be to the everlasting benefit of the firm adopting it.

Inattention to points of detail may arise either from carelessness or ignorance, or from a combination of both. Carelessness is absolutely inexcusable and merits but one punishment. There is no place for the careless man in the engineering world, and he would be better employed as the operator of a flying machine, as in this case his carelessness would soon meet with its own punishment. Ignorance may be due either to a want of knowledge of the requirements of the case, or, what is far more likely, to an inability to appreciate properly the *relative* importance of the details. I will illustrate what I mean by a simple example. Suppose that a man requires a 5-H.P. motor to drive a chaffcutter. Such a motor is a stock article with many firms, and would have been designed and manufactured with a view to its sale in competition in an open market. The details of its design may be quite good enough for ordinary work, in which the importance of the motor would be relative to its size, and where its failure for any reason would have no serious consequences.

Now consider the case of a 5,000-k.w. turbo-alternator, with which it is proposed to use a 5-H.P. motor for the purpose of removing the condensed steam from the condenser to the hot well, or where an even smaller motor is to be used for the oiling system. The relative importance of the motor is at once raised to that of the turbo-generator, as the failure of the motor would mean the shutting down of the larger plant, with all its consequential trouble. In this case, details of design and construction, which would be quite good enough when the failure of a 5-H.P. motor only meant 5-H.P. worth of damage or delay, would be quite insufficient when such a motor is a link in a chain with a 5,000-k.w. machine depending upon it. It is very difficult to make designers and manufacturers understand that the strength of a chain is only that of the weakest link.

Plenty of illustrations of the failure of large plant on account of defects in small auxiliaries could be given from actual experience, and the trouble may arise in several ways. The contractor is often the designer and manufacturer of only a portion of the plant included in his contract, and he frequently has to buy a number of auxiliaries from outside firms. When sending in his tender, in the first instance his concern is to obtain work for his own shops, and, in order that his offer may not be passed over on account of price, he generally selects the lowest price quoted to him by his sub-tenderers, without a proper regard to the quality of the material or its effect upon the working of his own plant. Although perhaps a specialist in his own particular

line of manufacture, he is not so familiar with the necessary details of the other plant or material included in the contract. It thus frequently happens that the contract as a whole is unsatisfactory, and gives a great deal of trouble.

To some extent this condition of things would be relieved if the consulting engineer would include in each contract only those articles which were made by the principal firms likely to tender. But an important question of responsibility at once comes in. Suppose that a large turbo-generator is required. From the purchaser's point of view this is one machine into which he puts steam at one end and from which he receives electrical energy at the other. The economy of the machine when working is determined solely by the amount or weight of steam required to give a certain electrical output. The turbine and the generator cannot be separated in this respect, as there is no practical method by which the output of the turbine can be measured mechanically. If separate contracts are made for the turbine and for the generator, not only is there a very real difficulty for the engineer to meet in arranging and settling the relative responsibilities of the two contractors, in the matter of assembling and erecting the combined machines, but the question as to which contractor is responsible, and to what extent, if the efficiency of the set is below the proper figure, becomes very complicated. Each contractor would doubtless allege that the plant of the other was at fault, and, in the absence of any practical method of ascertaining the exact mechanical output of the turbine and input to the generator, I cannot see how any other result than a compromise could be arrived at, no doubt without satisfying either party. It is an easy matter for a turbine builder to tender for his turbine coupled to another maker's generator (or *vice versâ*), because in that case he would be directly responsible to the purchaser for the result, and would have made his own arrangement with the other as to the proper division of any bonus or penalty. It is a difficult matter for the purchaser to order two separate pieces of plant and, while combining these, to keep separate the responsibilities of the two contractors. It is evident, therefore, that the only practical course is to order both turbine and generator from the same firm. To prevent the prime contractor (be he either the turbine or generator builder) from offering the cheapest machine he can obtain (which will probably be the worst) from a sub-contractor, it may be wise in some cases to accept a tender only from a firm which manufactures both articles. I have taken the turbo-generator as an illustration in this connection, but the same difficulty will arise in many other cases. In a pipe contract, the pipe-maker will perhaps include the cheapest valves or cheapest pipe covering which he can purchase, in order not to lose the contract for the pipes themselves. The customer suffers because the details of some of the most important parts are neglected.

So long as makers' designs differ, and they will always differ, both in price and quality, while trade competition lasts, so long will the engineer be unable to draw up a specification which will ensure the

supply of the very best article of its class. Many public bodies prohibit the issuing of specifications which include the supply of articles made by any particular manufacturer, and perhaps rightly so; but, unless the engineer is to make working drawings of every tiny detail of every part of the plant (which would not only be absurd but beyond his abilities in most cases), he can only specify in general terms. The result is that, as most public bodies will only accept the lowest tender, unless very exceptional reasons can be shown to the contrary, the engineer is frequently saddled with second-rate plant, weak in its details, and a constant source of worry and expense.

The engineer who is called upon to design a power station can see that the details of the design, as a whole, are in order; but he is often in a great difficulty in ensuring that the details of the various portions of the plant are satisfactory. He cannot be expected, for instance, to design the boiler, the turbine, or the generator, although he may design every detail of the steam and water-piping systems. He would not design the details of the high-tension oil switches, the transformers, or the measuring instruments, although the lay-out of the switchgear may receive his closest consideration. In other words, he is bound, from the very nature of the things, to accept the designs of contractors for many articles which have to be supplied as complete units in competition. Here he is frequently at variance with the engineer or draughtsman who designs for the manufacturer, who, in too many instances, has had little or no experience of actual operating conditions, and is called upon to design in such a manner as will ensure cheap manufacture, and a ready sale in the open market, rather than to give lasting satisfaction to the purchaser.

Attempts to cheapen the cost of production are laudable enough in themselves, and of no real detriment so long as the cheapened article is in no way inferior in actual performance to the more expensive one. But such attempts are dangerous when the designer is not also experienced in the details of manufacture and operation. A small point, which, to the designer, might seem of no real importance, is frequently of great value to the operating engineer. In the endeavour to turn out work cheaply, parts which have been designed and made for other machines and purposes are frequently "worked in," often merely to save the expense of new patterns. Instances of this can often be seen when machines of a larger size than have been before constructed are made. So-called "standard" bearings, governors, valves, brushes, switches, etc., etc., are used, because they happen to be in stock. Sometimes they answer well, but frequently they give a great deal of trouble because they are too small or not properly proportioned for their new work. Fortunately there are still some engineering firms who will only make the best that they know, who will not sacrifice that attention to detail which goes so far to make perfection, and who will not cut the price and the quality in order to secure present profit. Their reward may appear to be a long time in coming, but it most certainly will come if they can stand against cheap competition for the time being.

A few illustrations of the importance of attention to points of detail, which have come within my experience, may be of interest. A switchboard in an alternating-current station was fitted with a circular contact switch for varying the resistance in the exciter circuit of the alternators. A number of wires were led away from the back, being secured to the shanks of the contacts by thimbles and nuts in the usual way. The nuts were tightened up all right, but no steady pins had been provided for the contacts. A man was trying to straighten the large bundle of wires at the back, and the strain from the wires turned several of the shanks so that the contacts on the face of the board touched each other. The result was that the voltage of the station suddenly rose to a high value and the switchboard attendant was unable to reduce it before considerable damage was done to the lamps on the circuit. Fortunately, regulating switches of that type are going out of use, but no part of the electrical gear in a power station is more liable to give trouble on account of small things than those connected with the exciting system.

If machines are self-excited, such as direct-current generators, or if they are separately excited, such as alternators, the field windings of the direct-current magnets of the exciting machine are of comparatively small wire. Independent exciters are, of course, much worse in this respect, as they are of relatively small size. The connections between the various field coils are frequently made by means of small brass connectors with tiny thumb or set screws. These are not only very liable to work loose, but also to be caught by dusters or waste when cleaning operations are in progress. A loose or broken field connection can easily shut down a whole station, but because the exciter is a small machine and its field windings are small wires, only small attention is usually given to its details. A big alternator, however, is just as dependent upon its small exciter and upon its small field connections as it is upon the main steam supply from the boilers.

Low-tension direct-current generators frequently have their main terminals mounted upon blocks fixed to the side of the magnet yoke. This may be a convenient position for the connections in some cases, but, unless the terminals are protected, it is likely to be a dangerous one. I remember a case in a 550-volt tramway station where the overhead crane was worked by hand. A couple of men were merrily travelling the crane down the engine-room by pulling on the hand chain which was hanging near the wall. They had not paid particular attention to the position of the crab, or to the fact that the crab chains were hanging down to within a couple of feet of the floor. But the result was that one of the crab chains touched the exposed positive terminal of a running machine. There was a big flash, and the chain was afterwards found to have been electrically welded to the terminal on account of the arc set up. The circuit breakers on the switchboard were useless, as they were outside the circuit of the fault, and so the generator and its engine were pulled up and considerable damage done. Had attention to the detail of covering up the ter-

minals been given by the designer of the generator, the particular accident would not have happened, but the risk of a similar accident would have remained, as the adjacent brushgear and commutator could not have been protected. The men operating the crane were equally at fault as they had not paid any attention to the positions of the chains before moving the crane.

I have come across several instances where the switchgear was so connected that the blades of large knife switches controlling feeder circuits were alive when the switches were open. This is a very dangerous arrangement, and shows great carelessness or ignorance on the part of the designer. The relative positions of the instruments, switches, circuit breakers, etc., on the operating panels of switchgear are of great importance, not only for the quick and proper handling of the gear, but also for the safety of the attendants. It is quite surprising how many instances of bad design are still to be seen, even in modern work. Circuit breakers should be at the top of the panel, within hand-operating reach, but high enough to operate without the slightest danger. Indicating instruments, such as ammeters and voltmeters, should be on the line of sight, while switches should be conveniently hand high. Switches should never be used to open the circuit, but the circuit breaker should always be used instead. The switch should really be considered as an isolating plug for the circuit breaker. Some designers, however, seem to take a pride in dotting the apparatus indiscriminately all over the panels. I have seen fuses in a London station which, when they operate, must blow out directly on the line of the eyes of the attendant. I have seen circuit breakers fixed immediately under the brass cases of instruments, so that the arc would most probably destroy the case every time the breaker opened. I have also seen circuit breakers fixed so low that any rising arc from them would most certainly injure the attendant if he were near at the time. Surely such switchgear must have been designed by a draughtsman who was more concerned with what appeared to him to be a pretty appearance than by a real engineer who was familiar with the working of the apparatus. But in that event, what was the real engineer doing to allow such designs to be erected?

I suppose more mistakes have been made in the design of steam-pipe arrangements than in almost anything else. Everybody understands that to convey steam from a group of boilers to a group of engines, pipes must be used of a certain size and strength, depending upon the quantity and pressure of the steam. But the details of the arrangement upon which the successful working almost entirely depends are sadly neglected in the majority of cases. Such neglect is generally due to ignorance or lack of appreciation of the principles involved. Water will form and pipes will expand and no design will ever prevent it, but a good design will lead the water in a natural direction to places where it can do no damage, and will provide for the expansion to take place in such directions and to such an extent that no harm is done either to the pipe-joints or to the plant.

It is, or should be, common knowledge that all changes in the diameters of shafts, rods, or bolts which are subjected to bending stresses should be made gradually by means of rounded fillets, as there is a great liability to fracture if sharp or sudden changes are made. Particularly is this so at the line where bolt threads are started nearest to the head. I was once greatly troubled by the continual breakage of the bolts in the cross-head of a vertical engine. They snapped off like carrots just at the beginning of the thread every time. An entire cure was obtained by cutting a good round groove for a length of about $\frac{3}{8}$ in., so as to leave the thread standing, as it were, on the bolt, rather than cut into it. The beginning of the thread was equivalent to the starting of a crack. I have had the same trouble with the valve-opening rods of Corliss engines made by a well-known firm, and the same simple alteration got rid of all the difficulty. More recently the operating rods of some large throttle valves broke on several occasions, and always at the point where there was a sharp neck. By rounding the hollows the trouble was overcome, but such elementary faults in the design should never have been made by the makers. Not only were the accidents exceedingly annoying, but, by putting large units of plant out of action for the time being, they seriously risked the continuity of the supply from a large power house. Here was no case of money saved in manufacture by the adoption of the original design, but rather an inability to appreciate the relative importance of what, no doubt, appeared to the draughtsman to be only a small detail.

The end doors or covers of large surface condensers have to withstand a considerable internal pressure, due to the head of the condensing water, which, in turbine plant, is frequently 10 ft. or more. In one case which came under my notice the pressure was sufficient to cause the cover to bulge enough to break the internal water-joint across the diaphragm plate. The condensing water was thus partially bye-passed and rapid water wear was soon set up. In this instance stiffening bolts should have been provided across the line of the diaphragm, and these had afterwards to be fitted. In another case the condenser cover had been strengthened by heavy stiffening ribs, but, to make a neat external appearance, the ribs had been cast inside, where they interposed a considerable resistance to the free flow of the condensing water. As the customer had to pay for the power required to pump the condensing water through the condenser, his opinion of the designer was not improved by the discovery of the latter's artistic leanings.

A careful attention to the maintenance of the external brickwork of a boiler will, in many cases, save tons of coal per annum, by the prevention of small air leaks. Daily records of coal burned, water evaporated, steam used, and units generated, will, if properly analysed and properly applied, show many ways in which small and even great savings can be made. In fact, from the inception of the design to the daily operation of the plant, every point should be watched and

watched all the time. But the watching must be done with experience and knowledge, and a proper appreciation of the relative value of every item. Unfortunately, one cannot make a table showing the relative values in percentages which would apply to all cases, and, as a result, every case must be considered on its merits. For example, in a generating station with an annual load factor of only 10 per cent., the wages may amount to as high as from 25 per cent. to 50 per cent. of the coal bill, depending upon the local price of fuel. In such a station it would, in all probability, not pay to go to great refinements in the shape of expensive condensing plant, involving extra labour for its attention, or additional capital charges, as the gain in economy in coal consumption might easily be counterbalanced by the extra wages bill and the extra costs of maintenance and capital. But in a generating station with an annual load factor of, say, 50 per cent., the coal bill can easily be as high as 80 per cent. of the total running costs, and the labour only from 10 per cent. to 12 per cent. of the coal bill. In this case it would pay to save coal by all and every means, and it would be false economy to stint the labour, or to omit any refinement in measuring steam and coal consumption, if the coal bill could be reduced thereby. In this connection I would mention a piece of apparatus which, in my opinion, would, if properly and intelligently used, be the means of making great economies in many power stations. I refer to the Lea water recorder. This, as you no doubt are all aware, consists of a weir, with a V notch, over which the condensed steam is passed on its way to the hot well. By means of a float the height of the water is indicated, and a continuous record obtained on a chart. The V notch has a well-known law, easily proved and checked, and the indications of the recorder are remarkably accurate. By having a separate condenser, each with its Lea recorder, for each unit of generating plant, the steam consumption can be ascertained at any instant by a glance at the indicator, while the total weight of steam used during any given time can be plotted from the recorder chart and compared with the total output of the plant for the same period. Little faults frequently occur, both in reciprocating engines and turbines, which do not show themselves in any striking manner, and so they continue until some day it is noticed that the coal consumption is mysteriously rising. Then the problem is not only to find what the trouble is, but where it is. The use of a Lea water recorder on each condenser would have shown instantly which set was at fault, and, in all probability, given the clue to the defect.

While a good engineer is always characterised by a keen attention to matters of detail, it by no means follows that a man who watches trifles is necessarily a good engineer. There is such a thing as straining at a gnat and swallowing a camel, and the engineer should cultivate strongly a proper sense of proportion. To look merely after the pence and to expect the pounds to take care of themselves may be all right under some circumstances, but, in engineering designs and work, this would indeed be penny wise and pound foolish. Michael Angelo's

loving care of the trifles, when completing his statue, would have been of small avail if the figure generally had not been properly proportioned and of good design and workmanship; and the engineer must learn first to design properly on broad lines, and to appreciate the relative importance of the main points of the scheme, before he can give those finishing touches which are the hall-mark of the work. He must learn to stand back and view his work, as a whole, from he distance, as well as to apply the microscope to the details. To see the beauties of the design of the Houses of Parliament a man must look at the building from the opposite side of the river Thames as well as from the adjacent footpath. The engineer, therefore, should inspect his work from all sides and from all standpoints, but, before he can attend to details, his main designs must be properly worked out. It is of little use to have a perfect system for draining the steam pipes if the boilers are too small to generate enough steam to drive the engines. The use of CO_2 recorders to analyse the flue gases is very proper and necessary, but, if the coaling arrangements are defective, the coal supply may run short, and there may be some day no gases to test.

An appreciation of the importance of attention to detail should not lead the engineer to make the mistake of over-elaboration. Simplicity should be the keynote of the design, and, while nothing can be too good, so far as quality is concerned, an otherwise good scheme may easily be spoiled by overloading. Success in working is far more certain when nothing is included in the general design except that which is really necessary, because the additions frequently introduce the very troubles which their use is intended to avoid. The skill of the engineer is shown by his ability to distinguish between what is necessary and what is not. But, when it is decided what is necessary, its details should have all the care and attention which it is possible to give.

To reach high, the engineer must aim high, and therefore he must be a man with high ideals. Nothing should be too good for him, either in his work or in his reward, and, in attending to the details of his daily task, he should remember the words of the poet who said—

> "Oh, the little more, and how much it is!
> And the little less, and what worlds away!"

JOURNAL

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Proceedings of the Five Hundredth Ordinary General Meeting of the Institution of Electrical Engineers, held at the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, January 13, 1910—Dr. GISBERT KAPP, President, in the chair.

The minutes of the Ordinary General Meeting held on Thursday, December 16, 1909, were taken as read, and confirmed.

The following list of transfers was announced as having been made since the last meeting, and it was ordered that it should be suspended in the Library :—

TRANSFERS.

From the class of Associate Members to that of Members :—

Percy M. Bennett.
Charles W. Durnford.
Ernest T. Goslin.
James W. Harris.
Karl K. von Krogh.
James McLachlan.
Arthur H. Pook.
William Angus Scott.
William Andrews Tester.
Ernest T. Williams.

From the class of Associates to that of Members :—

Hugh Sebastian King.
William D. N. Morgan.
Frederick Ryan.

From the class of Students to that of Associate Members :—

Gordon Donovan Adam.
Henry B. Bennett.
William Campbell Crockatt.
Hugh Stanier Reid.
Charles Owen Silvers.
Maurice G. Tweedie.
Francis W. Wilson.

Messrs. E. R. Carr and J. T. Morris were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

As Members.

Alexander Anderson.
Professor Louis Anthyme Herdt.
Peter William Sothman.
Richard Ernest Winkfield.

As Associate Members.

Percy Montague Baker.
Francis Edmund Bayley, B.A.
William Bent.
William Henry D. Bostock.
Percival Raymond Boulton.
George Bowyer.
William Campbell Chappell.
Walter Francis John Cosser.
William Seward Cunningham.
Donald Steer Duff.
Thomas Murthwaite Dutton.
Thomas William Ellis.
Raymond Fitzgibbon Fry.
William Alfred Fullalove.
George Gordon Gale.
Henry Gobie.
Arthur Gordon Grier.
Robert Leigh Griffin.
Arthur Benjamin Hart.
Ambrose Hartley Hull.
James Henry Hull.
Herbert Henry Johnson.
Reginald Johnson.
Cecil Gurth Kirkus.
Henry Kitchen.
Sydney Calver Leggett.
Henry Airton McInnes.
Duncan McLennan.
Richard Murray.
Robert Nimmo.
Henry Ogilvie.
Percy John Pybus.
Edward Lancelot Ransome.
Joseph William Ray.
Oswald Lowden Record.
George Bradley Roberts, Major, R.E.
Julian Walter Saaler.
Reginald Sherley-Price.
Maurice George F. Temple.
Herbert Gibson Townsend.
Percival Wilberforce Turner.
William Tyler Wardale.
Richard Albert Weaver.
Charles Whillis.
James Herbert Whiteley.
Bertram Wood.
Harry George Young.

As Students.

Meer Laig Ali.
George Dyson Aspland.
William Herbert Badger.
Gordon Pullman Bailey.
Arthur Barratt.
Harold Edward Bellamy.
Brian Stuart Benning.
John Ernest Blair.
John William P. Chalmers.
William Harold Clarke.

As Students (continued).

Alfred Coleman.
Robert Harold Collier.
John Lowry Hone Cooper.
Michael Ralph de Cordova.
Victor Cyril Dixon.
George Westbrook Edward.
Frederick Forester Elliott.
Charles Campbell Elsworth.
Joseph Gilbert.
Edgar George Grant.
Ernest Grimshaw.
Robert William Gunter.
John Philby Guy.
William Ashton Hatch.
Frank Hayter.
Francis G. Heymerdinguer.
George Ingram.
James Gardner Jamieson.
Thomas William Jeffreys.
Rowland Stanley Jull.
Claude Hilton Keith.
James Mowat Knight.
Frank Philip Sleigh Lacey.
Eric Lancelot Lindquist.
Angus Dow Mackinnon.
Archibald MacLean.
Gervais Bushe Manson.
William Rowland Millar.
John Alfred Nunn.
Louis Henry Page.
David Edwin Parton.
Percival Osborne L. Pellowe.
William James Pickersgill.
William Henry Rean.
Charles Reid.
Ralph Elwyn Ricci.
Frederick George Ride.
Henry Nelsey Ridgway.
Andrew Kean Roxburgh.
Albert Rushton.
Henry Humphrys Scotland.
Harry Gilkes Sharp.
Percy Edward Stevens.
Reginald Edward Stradling.
Aubrey Bertram Stratford.
Samuel Herbert Temple.
Alexander Charles Thompson.
Arthur Carlyle Timmis.
Henry Stanley Tisshaw.
Lionel William Tivy.
Alexander Henry Watson.
Archibald Parker Welch.
Claud Walpole Westwood.
Arthur George Wheeler.
Edwin Victor Winstanley.
Henry Percy Young.

THE SECOND KELVIN LECTURE.

THE WORK OF LORD KELVIN IN TELEGRAPHY AND NAVIGATION.

By Professor J. A. EWING, C.B., F.R.S., Member,
Director of Naval Education.

(*Delivered January* 13, 1910.)

When Lord Kelvin died, on December 17, 1907, he was in his eighty-fourth year. Most of you have some personal impression of him: you have seen him and probably heard him speak. The younger of you have known him only as an old man, still marvellously vigorous and alert for all his weight of years, but none the less enfeebled by age and often distracted by pain. To the last he retained his interest in science, his imagination and insight, his faculty of invention, his sympathy in other men's work. With a fine courage he had accepted the Presidency of this Institution for the third time, in the year of his death. But no one who saw only the venerable figure of these last years can realise the tremendous force, the overwhelming vitality of mind and body that characterised him in his prime. To be with him then was to be as it were in the presence of a whirlwind compelling to activity all who came within its influence. But the comparison, apt as it is in some aspects, fails altogether in another. A whirlwind makes no appeal to the affection, and so the phrase conveys nothing of Lord Kelvin's sweetness and charm. His nature was one of transparent simplicity. He was one of the few very great men whose greatness is not greater than their goodness. To know him well was to love him; to know him better was to love him more. To work under him was an inspiration. It was not simply that one was amazed by his genius, stimulated by his suggestion or example, infected by his enthusiasm, fired by his untiring energy, moved by his passionate sincerity. He was ever thoughtful for others, encouraging, sympathetic, courteous, modest, reverent. His more tender personal qualities bred a sentiment for which devotion is not too strong a word.

When the Council honoured me with an invitation to give this lecture, I felt it was a task not to be declined. It is fitting that one who had the privilege of assisting Kelvin in the days of his high activity should tell of him to the younger generation. To have known him as he was then is one of the consolations for growing old.

It is just forty years since I first came under his spell. A schoolboy at the time, with an appetite for physical experiments that found but meagre gratification, I happened to be visiting in a house where there were some bound volumes of the magazine *Good Words*, which, as the

motto on the title-page said, "are worth much and cost little." The motto justified itself to me, for in one of the volumes was an article which went far to determine the current of my life. It was on "Energy," by Sir William Thomson and Professor Tait, dated 1865—one of the first-fruits of that collaboration which, later, produced Thomson and Tait's *Natural Philosophy*. The article expounded in a simple way the doctrine of the conservation of energy, its capacity for transformation, its tendency towards dissipation. Those ideas were new then, and to me they came with the force of a revelation, opening my eyes to the unity of physical phenomena. It seemed as if reading the article made such vague and shadowy conceptions as I had in physics and mechanics crystallise into a coherent philosophy. To you, who have been fed on primers in which all these things are treated as established commonplaces, this may be unintelligible; to me it was very real. You live in the glare of noonday, but it was then the dawn, and it is in the freshness of dawn that one regards the sun. So impressed was I that here was a new gospel, that I copied out the article in manuscript. It had cost nothing, but it was worth much.

A year or two later I went to the University of Edinburgh and attended the lectures of Tait and of Fleeming Jenkin. They imbued their pupils with a wholesome sense of the greatness of Thomson, and I well remember that the introductory lecture of Tait's course referred to a discovery of Thomson's, just then published, regarding the distinctive character of ripples and waves. At the end of the session in 1872 I was invited by Fleeming Jenkin, who, besides being Professor of Engineering at Edinburgh, was Sir William Thomson's partner in consulting work relating to submarine telegraphs, to become one of the firm's assistants. Such a chance was not to be missed. In this way began a personal connection with Kelvin which lasted, on that basis, for several years, and continued on the wider basis of discipleship and friendship to the time of his death.

In later years I have many vivid memories of his visits to the engineering laboratory at Cambridge, sometimes—three times in fact—to perform a ceremonial function such as the opening of the laboratory itself or of a new wing, but much oftener just to see what was going on. It was a joy to show him any research that happened to be in progress, to hear his quick questions, going straight to the heart of the matter, to have his kindly comment, to witness his unfeigned interest—his enthusiastic delight—when the thing struck him as new and good. His attention and curiosity aroused, he would take no note of time, and the patient Lady Kelvin at his side would try gently to recall the claims of some distant host, some forgotten engagement, some train that should be caught.

The first task of the Kelvin Lecturer is one of selection. In the initial lecture, as was fitting, Professor Silvanus Thompson gave an admirable general survey of Kelvin's life and work. We are glad to think that this will soon be followed by the publication of a biography in two volumes. Professor Thompson has been so kind

as to show me advance proofs of his forthcoming work, and to give me access to other material, which has helped much in the preparation of this lecture. May I in thanking him add a word of appreciation of the way in which he has carried out an immense and difficult undertaking? The public will soon be in a position to judge for themselves of the result: they expect much of Professor Thompson, and it is safe to say that they will not be disappointed.

Lord Kelvin's work was great and many-sided. We might compare it to the cathedral in some crowded mediæval city where no place can be found commanding a general view. You approach by one narrow street or another, seeing from each only some portion of a particular face of the building. The Kelvin Lecturer has, as it were, to select his view-point, conscious that he must concentrate his attention on what is after all but a small part of a gigantic whole. The lecturer might, for instance, take up the mathematical work of Kelvin in the theory of electrostatics, in the theory of magnetism, in the theory of elasticity, in hydrodynamics, in the wave theory of light, or his contributions to thermodynamics which included the establishment of an absolute scale of temperature and the enunciation of the principle of the dissipation of energy, or again his experimental work on the electrodynamic quality of metals, his speculations on the structure of matter, his views on the age of the earth, his share in fixing the electrical units, or, on the more practical side, his electrical measuring instruments, from the electrometers of the early days to the ampere balances and wattmeters which he designed when the need for such instruments became apparent with the growth of electrical engineering. Any one of these subjects, or others that might be named, would provide a more than ample text. To-night I have selected two portions of Lord Kelvin's work as the most suitable to bring before you, namely, his work in submarine telegraphy and in navigation. Both of these are practical matters which appeal to members of this institution. They illustrate well the bent of his genius as an engineer. In both of them he made inventions of first-rate importance—inventions which not only met an immediate requirement, but have stood the test of time. And an additional reason for the selection is the personal one that in both telegraphy and navigation it was my good fortune as one of his young assistants to see some of his inventions in the making.

His connection with telegraphy had begun long before, when he was only thirty years of age. It dates from 1854, and to appreciate rightly the part he began to play then I must ask you to go back as far as 1850, the year of the earliest submarine telegraph. It was in August, 1850, that a line consisting of a single copper wire, insulated by gutta-percha, wound on a great reel on the deck of a steam tug in Dover Harbour, was laid from Dover to Calais. There was no sheathing or protection of any sort; the line was what we should now call a bare core, and so light was it that lead sinkers were attached at every hundred yards to ensure its going to the bottom. In a few hours it was cut by the anchor of a fisherman, who took home a piece to show to his family as a curious

new kind of seaweed, but during its brief life it gave the operators much food for thought. Accustomed only to the clear, sharp signals of land lines, they could make nothing of those got from the cable, and Mr. Willoughby Smith tells us how at each end of the line it was regretfully concluded that the operator at the other end must have been lunching not wisely but too well. This was the earliest experience of the effects of electrostatic induction in retarding the signals and altering their character. The cable is equivalent to an extended Leyden jar of large capacity, and at every application of the sending battery there is a gradual charging up, so that the signal current which arrives at the distant end does not at once reach its full strength. And, further, when the contact with the sending battery stops the current does not at once cease, but tails off slowly as the cable discharges the electricity it has accumulated. The current accordingly arrives in the character of a wave, slowly rising to a maximum value and then slowly subsiding, each time a signal is sent.

In a short cable this causes little trouble; it only makes the process of signalling a little slower, but the instruments which serve on land lines may still be used. A successful Dover-Calais cable properly covered with a protecting sheath was laid in 1851 and was soon followed by other short lines. The general character of the electrostatic charge in a cable was explained by Faraday, and it was experimented on by Latimer Clark in a cable, 110 miles long, laid to connect England with Holland. But no one knew then in what manner the retardation of signals to which it gives rise depended on the electrical characteristics nor how it would be affected in cables of different lengths or with different dimensions of core. It was in 1854 that Thomson's attention was drawn to the subject by Stokes, following on a conversation at the British Association, and in this way began the connection with submarine telegraphy which was to prove of momentous import.

You must think of Thomson then as a young man of thirty—already for eight years a Professor at Glasgow—unknown to the general public, but with a European reputation among scientific men for his far-reaching investigations in the mathematical theory of electricity and in thermodynamics. Helmholtz, whom he met for the first time a few months later, thus records the impression he produced: "I expected to find the man who is one of the first mathematical physicists of Europe somewhat older than myself, and was not a little astonished when a very juvenile and exceedingly fair youth, who looked quite girlish, came forward. . . . He far exceeds all the great men of science with whom I have made personal acquaintance, in intelligence and lucidity and mobility of thought, so that I felt quite wooden beside him sometimes."

Thomson attacked the problem with characteristic ardour, and in less than twelve days he sent a complete solution to Stokes, which was published in fuller form in the Proceedings of the Royal Society for May, 1855. In this paper he points out that the effect of electrostatic

induction is to make the flow of electricity in a cable correspond to the flow of heat in a solid conductor as investigated mathematically by Fourier. He formulates the equations and draws what is called the *curve of arrival*, the curve, namely, which shows in what manner the current gradually reaches its full value, at the distant end of the cable, when contact with the battery is made at the sending end. He also shows how the current falls away when the battery is removed and the cable is put to earth. In the diagram (Fig. 1) the full line is the curve of arrival. For a certain interval *a* after the battery is connected practically no effect is felt, but soon after that the current becomes of sensible magnitude. It continues to rise; and after a time nearly equal to

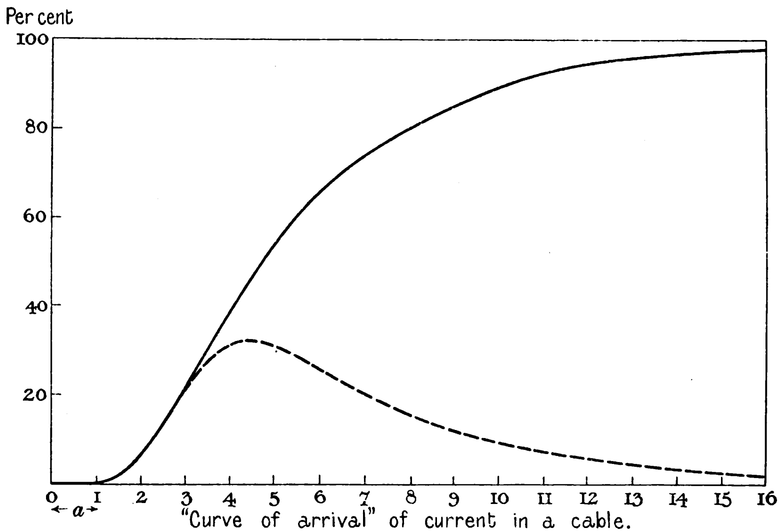


FIG. 1.

5*a* it has attained half its final value; after a time 10*a* it has come within 10 per cent. of the final value, and its rise has then become very slow. To reach completely the full value an infinitely long time would be required. The dotted line shows how the current at the distant end decreases when the sending end is removed from the battery and put to earth. In this case the contact has lasted for the interval 3*a*. When it ceases the current at first continues to increase, soon passes a maximum, and then gradually tails away, requiring an infinitely long time altogether to disappear.

Thomson showed that the quantity *a* varies directly as the product of the capacity of the cable and its resistance. Since both the capacity and the resistance increase directly with the length, if we compare two cables with the same core but of different lengths, *a* will depend on the square of the length. Hence also the time taken by the current to reach

any particular fraction of the full value will vary as the square of the length.

This result of the theory was of fundamental importance. It was also, at the time, of particular interest, for the project was then beginning to be mooted of connecting England and America by wire. The only experience available as to speed of signalling was on short cables, and in passing from them to a line 2,000 miles long the "law of squares," as it was called, seemed at first to give little prospect that signalling across the Atlantic could be accomplished at a speed that would be commercially practicable. The "law of squares" was challenged by Mr. Whitehouse, who was interested in the Atlantic project. He failed to grasp Thomson's reasoning and its results, and misinterpreted some experiments of his own in a sense opposed to Thomson's theory. Thomson replied in two letters to the *Athenæum* (October and November 1856), pointing out that Whitehouse's experiments, so far as they went, only tended to confirm his own conclusions, and emphasising the fact that a remedy for inconvenient slowness of action was to be found partly by increasing the diameter of the conductor, thereby reducing the resistance, and partly by increasing the diameter of the gutta-percha coat, thereby reducing the capacity. It appears to have been these controversial letters which led to Thomson's taking a share in the earliest attempt to lay an Atlantic cable, the attempt of 1857.

Two practical points at once engaged his attention. One was the question of copper resistance. "In measuring the resistance of wires manufactured for submarine telegraphs," he writes in June, 1857, "I was surprised to find differences between different specimens so great as most materially to affect their value in the electrical operations for which they are designed." He looked at first for an explanation of these differences in the stranding of the wires or in the effect of covering with gutta-percha, but after various experiments (his laboratory was then a disused wine-cellar in the old Glasgow college) he was forced to the conclusion that the differences lay in the nature of the copper itself: that one might find specimens with twice or even more than twice the resistance of the best. Having discovered in this way the distinction between high conductivity copper and copper of other sorts he insisted on the use of copper of the highest conductivity and on the importance of systematic testing, though this came too late to affect the manufacture of the cable which was being prepared for the abortive attempt of 1857.

The other point which he took up was the invention of a method of signalling adapted to the character of the "curve of arrival." But before speaking of that, let me say a word as to his position among the Atlantic cable pioneers.

The Atlantic Telegraph Company had been formed in October, 1856, and in December Thomson joined the Board as one of the directors, elected to represent the interests of Scottish shareholders. Charles Bright was engineer-in-chief, and Whitehouse, who had misunderstood and disputed Thomson's electrical results, was electrician.

Thomson had no technical position beyond being a director. Writing to Helmholtz in December, 1856, he says: "The Atlantic Telegraph is now in the process of manufacture. Two thousand five hundred miles of cable are to be finished and ready to go to sea by the end of May, and if no accident happens electric messages will be passing between Ireland and Newfoundland before July. I have been appointed one of the directors, and what I feel most anxious about now is the laying of the cable. The plans must be better arranged than they have been in all such operations hitherto, in which there have been almost as many failures as successes. However, the circumstances are in some respects more favourable than they have been in former cases. We have a soft level bottom (consisting of fine sand and microscopic shells) the whole way across, nowhere more than 3⅓ miles deep, which will be much better than the Alpine precipices and valleys below the waters of the Mediterranean. The cable is much lighter than any hitherto laid, weighing only 18 cwt. per mile, or in water only 10 cwt. The practical men engaged have all the experience of previous failures, and it is to be hoped have learnt some of the causes and will know how to avoid them. Altogether I think there is a good chance of success."

That hope was not destined to be immediately fulfilled. To lay the cable it was coiled on board two ships of war, the British battleship *Agamemnon* and the United States frigate *Niagara*. On August 5, 1857, the shore end was landed at Valencia and the *Niagara* began to pay out, the intention being that her section should be laid first and the *Agamemnon* should continue the work after making a splice in mid ocean. But the paying out gear was very crude: the brake for maintaining a proper tension in the cable was difficult to regulate, and after 300 miles were laid there was a mishap at the brake and the cable parted in 2,000 fathoms. The ships returned to Devonport: the cable was stored for the winter, new machinery was designed, and some 700 miles of fresh cable were manufactured against the next attempt, to be made in the following year.

Thomson had joined the expedition at the request of his brother directors and was on board the *Agamemnon*. He came back full of ideas as to both the electrical and the mechanical sides of the great problem.

On the mechanical side he had worked out, for the first time, the theory of the forces concerned in the laying and lifting of deep-sea cables; this was published almost immediately after his return. Let me give you a brief sketch of the results of this theory.

A cable paid out from a ship going at uniform speed does not hang as a catenary but takes the form, as its sinks, of a straight line stretching at a uniform slope from the ship's wake to the point far in the rear at which it touches the bottom. This is because each part of the cable in sinking through the water attains almost immediately a constant velocity of descent against the resistance which the water opposes to its motion. Imagine a ball, heavier than water, to be

dropped from a ship. It will after sinking a foot or two attain a practically uniform velocity and keep that until it reaches the bottom. Imagine now a ship to drop a series of such balls, at regular intervals, while she steams ahead at a steady speed. At any instant the depth through which each ball has sunk will be proportional to the time which has passed since it was dropped, and therefore to the distance run by the ship, and hence a line joining the successive balls will be a line of uniform slope. The continuous cable behaves in this respect like the row of balls, but with this important difference. Each ball sinks vertically, it has no tendency to do anything else. But the cable tends not only to sink, but to glide along the direction of its own length, just as a rope resting on an inclined plane tends to glide down it. A certain amount of such gliding is desirable, indeed necessary, for it secures that the cable will be laid with a sufficient percentage of slack to accommodate itself to any inequalities on the bottom, and to provide for the possibility of its being raised, should that be required. It is the function of the paying-out brake to apply just so much retarding force as will allow the right amount of this gliding to take place, and not too much. Taking any point P in the cable (Fig 2), the actual motion

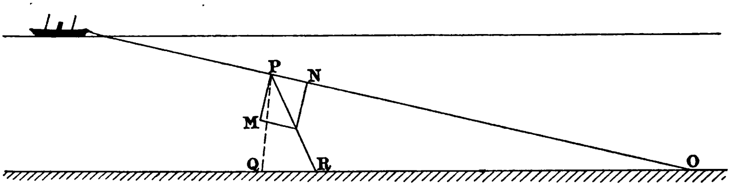


FIG. 2.

in settling to the bottom may be regarded as made up of two components, one a component transverse to the direction in which the cable lies (P M) and the other the longitudinal or gliding component P N along that direction. The result is to give a resultant motion which brings the point P along the line P R to the bottom at R. If there were no slack, the movement would be along P Q, where O Q = O P, but even in that case there would be a small amount of longitudinal motion, since P Q lies to the right of the normal component P M. As cables are actually laid there may be 10 or 12 per cent. of slack, and this means a considerable velocity of gliding motion. In a cable of the type which was afterwards successfully laid across the Atlantic the straight line had a slope of about 1 in 8½—in other words, with a depth of 2 miles there were 17 miles from the ship to the place where it touched bottom. In the gliding motion down this long slope the frictional resistance of the water is an important factor: it reduces very much the retarding force needed at the brake. If it were simply a question of holding the cable from gliding down the slope at all, the retarding force would be equal to the weight, in water, of a length of cable equal to the depth. In fact, however, it is

about half that, the other half being accounted for by the frictional resistance which the cable experiences in gliding down the slope.

In the early summer of 1858 the cable squadron was again ready to put to sea. New paying-out brakes had been devised. Thomson had succeeded, with much difficulty, in getting systematic tests of the conductivity established during the manufacture of the additional 700 miles. And, most important of all, he had invented a

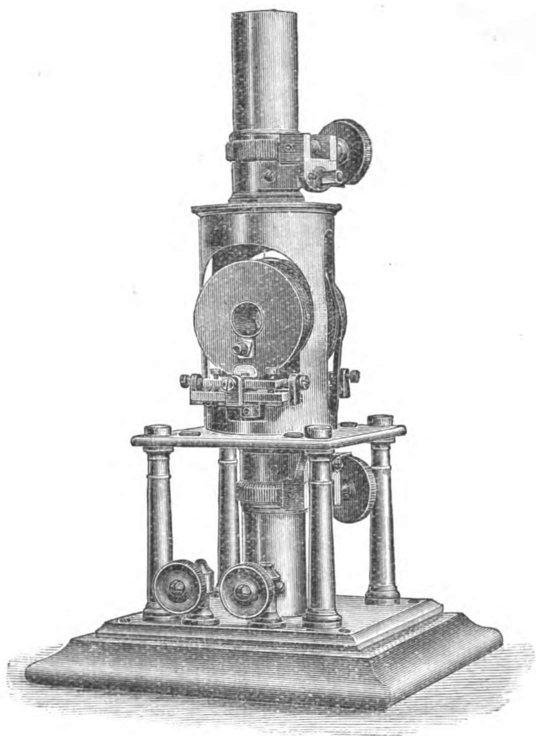


FIG. 3.—Mirror Galvanometer, Marine Pattern, used on board the *Niagara*, 1858.

new signalling and testing instrument which was to make Atlantic telegraphy commercially practicable. This was the mirror galvanometer, the first description of which is found in his patent of 1858. Mr. Whitehouse, still officially the electrician of the Company., had provided an elaborate paraphernalia of relays and induction coils which experience was to prove useless. Just before the ship sailed there was handed to Thomson on board the ***Agamemnon*** a precious package brought hot-foot from Glasgow by his assistant, Donald Macfarlane. This was the earliest marine mirror galvanometer—one

of a pair completed only just in time. The other went to the *Niagara*. It is now preserved in the museum of the Glasgow University laboratory, and here we have a photograph (Fig. 3). This is the actual instrument by which a message was first received across the Atlantic.

In its simple form the mirror galvanometer consists of a tiny circular glass mirror no bigger than a threepenny piece, to the back of which are cemented two or three pieces of steel watch-spring flattened and hardened and permanently magnetised. This is hung by a silk fibre in a horizontal tube a little bigger than the mirror itself; the suspending fibre, which is quite short, passes out at a hole in the upper side of the tube and is secured there by a drop of wax or cement. Mirror and magnets together weigh less than a grain. The tube, with the mirror in it, is pushed into the centre of a coil through

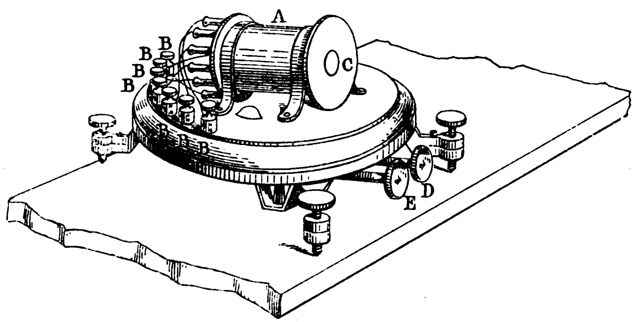


FIG. 4.—Mirror Galvanometer shown in the Patent of 1858.

The coil A is divided into a number of sections, with terminals B B B.
Light reaches the mirror through the opening C.
D and E are handles for adjusting the position of a directing magnet underneath the base-board.

which the current passes. Outside there is an adjustable magnet, or pair of magnets, to give a suitable controlling field. A beam of light from a lamp falls on the mirror and is reflected on a scale. Thus we have, as it were, a very long pointer to exhibit the deflection, entirely destitute of inertia. Fig. 4, showing a simple form of mirror galvanometer, is copied from the patent of 1858. The marine form, which is also described in that patent, and of which Fig. 3 is an example, differs in the method of suspending the mirror. The suspender is a long thread held tight at top and bottom, to the middle of which the mirror is attached. This makes it independent of gravity, so that it is not disturbed by the motion of the ship. The instrument is sensitive in responding to the slightest current or fluctuation of current: there is no friction to be overcome, and almost no inertia in the moving parts.

These are the characteristics which Thomson aimed at in this remarkable invention, for he saw that they were required as a direct result of his theory.

Go back to the "curve of arrival," and you will notice that to make rapid signalling practicable, we must be content to deal with only the earliest stages in that curve. Even in later Atlantic cables the time unit *a* is about the fifth of a second: in the original cable of 1858 it was much longer. If the transmission of a signal required a time equivalent to many times *a* the number of words got through per hour would be impracticably small. Hence also the impulses constituting successive signals must follow so quickly on one another's heels, that the cable has no chance to get rid of the effects of one before the next is upon it, and the next. Take, for example, the letter *h* consisting of four successive impulses of the same sign. If we were to form each of them by a battery contact for the period *a*, followed by an earth contact for the period 2*a*, we should get a curve of arrival like the figure (Fig. 5), where you see well this super-

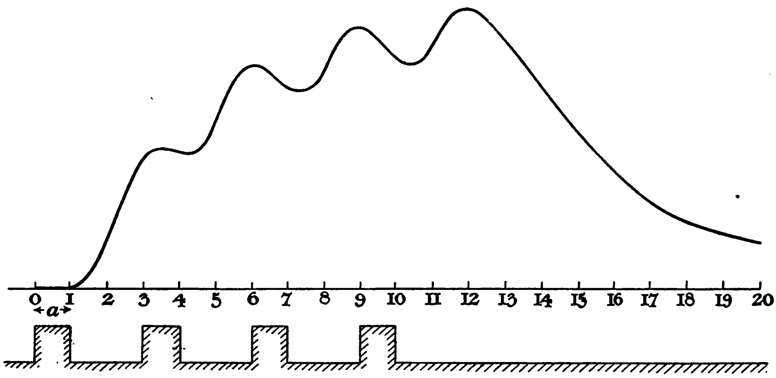


FIG. 5.

position of effects; and if we try to quicken up the speed by reducing the earth contact to *a* as in Fig. 6, the confusion becomes so great that it takes a practised eye to distinguish that there are four impulses in the resulting curve. To exhibit these as signals it was clearly impossible to use an instrument like an electromagnetic relay of even the most sensitive type: you must have an indicator which will follow every fluctuation in strict proportion, not requiring to come back to zero between the impulses, frictionless, and not introducing any distortion by virtue of the inertia of its own moving parts. This Thomson achieved by his invention.

We have no time to linger over the story of the cable of 1858. This time the two ships, after encountering a storm of great severity in which the coiled cable suffered severe damage, met in mid ocean, spliced the cable, and began to pay out simultaneously, the *Agamemnon* steaming towards Ireland and the *Niagara* towards Newfoundland. The cable broke when only 6 miles were paid out. Again the ships met, to make a fresh splice, and again the cable failed when some

80 miles had run out. A third attempt promised better, for some 200 miles were laid, when again the cable broke, this time at a place where it had been injured in the storm. The ships returned to Queenstown: Bright, Thomson, and the other leaders, disappointed but not disheartened, advised the Board to order a fresh attempt. Their advice was taken. The ships once more met at the mid-ocean rendezvous, and this time success crowned their efforts. On August 5th both ships completed their task, and the ends of the cable were brought to land.

Scarcely had the enthusiasm awakened by this great event begun to subside when it was apparent that all was not well. The Irish end of the cable had been handed over to Mr. Whitehouse,

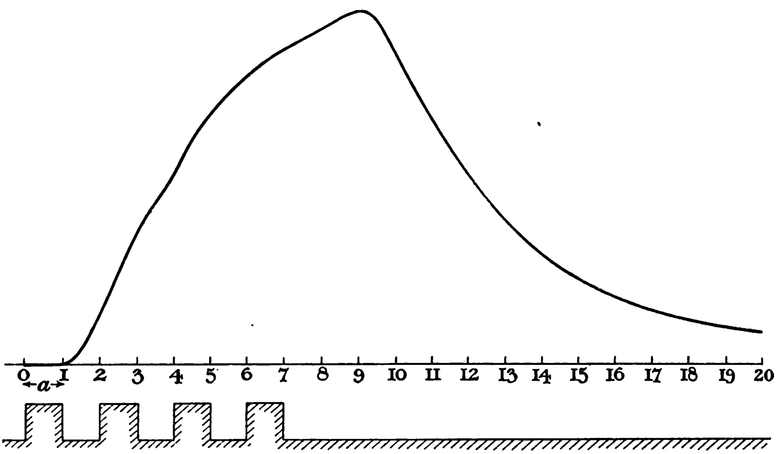


FIG. 6.

who attempted with little or no success to establish communication by means of his own signalling instruments. It was only when the galvanometer of Thomson was resorted to with a simple Daniell battery to send the current that messages were transmitted. The Board, dissatisfied with Whitehouse's action, directed Thomson to take complete charge. Various important messages passed, but the tests showed that the insulation of the cable had broken down: a bad fault developed, which had doubtless been intensified if not produced by the high-tension induction coils used by Whitehouse. The signals grew more and more feeble and in a few weeks the cable altogether ceased to speak.

It never spoke again, and not till 1865 was the attempt made to lay a new Atlantic cable. By that time much had been accomplished. It was in the intervening years that the work of establishing standards for electrical measurement was undertaken by a Committee of the British Association. The Committee was appointed at the instance of Thomson, and he took a prominent part in its work. Besides this,

the cable engineers were busy and were gaining experience from lines laid in other places. Methods of systematic testing were devised: a type of cable was designed which was better adapted than before to bear the strain of laying, and especially the much severer strain of picking up, and material improvements were made in the paying-out machinery. Thomson encouraged a fresh attempt. "What has been done," he said, "will be done again. The loss of a position gained is an event unknown in the history of man's struggle with the forces of inanimate Nature." On the financial side it required some faith and courage to engage in the enterprise at a time when it was said that out of 9,000 miles of cables already laid, only 3,000 were in working order. We cannot wonder that there was some delay.

In 1865 the *Great Eastern* was available for laying the cable. Thomson, along with Cromwell Varley, went as a consulting expert on behalf of the Company. Twelve hundred miles were successfully laid, and then a fault showed itself: picking up was begun, but in manœuvring the ship the cable parted in deep water. Attempts were made to recover it by grappling; three times it was hooked and brought part of the way to the surface, but the shackles used to couple up successive lengths of the grappling rope were too weak to stand the strain. Grapnel, rope, and cable were lost, and the ship returned with the task unfinished, but with every one now full of confidence not only that a sound cable could be laid, but that the lost cable could be found and lifted.

In 1866 the thing was done; an entirely new cable was laid with complete success, and then the *Great Eastern* with her consorts proceeded to the lost end of the cable of 1865, and began once more to fish in water over 2,000 fathoms deep. A fortnight passed before the watchers at Valencia saw any sign: then the spot of light began to flicker, and presently the flickerings shaped themselves into letters and words. The cable had awakened to life. A few days more and it too was complete.

Throughout the operations Thomson was in the ship; Varley remained at Valencia. Thanks to their labours, and to those of Mr. Willoughby Smith, the contractors' electrician, the appliances for testing on board ship had been brought to a degree of perfection that left nothing to be desired. By this time it was generally recognised that the credit for Atlantic telegraphy, regarded as an electrical achievement, belonged to Thomson, though in his characteristic manner he would, when speaking of the subject, dwell on the parts played by others. Along with Mr. Canning, the engineer of the expedition, and Captain Anderson, who commanded the *Great Eastern*, he received the honour of knighthood.*

For a time his mirror galvanometer remained the only instrument by which conversation could be carried on. He soon proceeded to

* Sir Charles Bright, who was engineer-in-chief in the earlier expeditions, did not take part in the expeditions of 1865–6, but continued to advise one of the companies concerned. He was knighted on the completion of the 1858 cable.

design a substitute for it, which should give a record of the successive electric impulses instead of merely exhibiting them to the watchful eye of a skilled clerk. To secure greater power in the movement of the indicator he inverted the function of magnet and coil, making the coil the movable piece and the magnet the fixed piece. The coil was, therefore, made very light: the magnet, which being stationary might now be very heavy, was made exceedingly strong and was arranged so that the coil lay in an intense field between its poles. The movement of the coil actuated a very light pointer or rather pen in the form of a siphon-shaped tube of fine drawn glass, from which ink was deposited on a running paper band. Here we find the earliest example of the moving coil type of galvanometer, often called the D'Arsonval type by those who do not recognise its real origin. It is a type now familiar in many practical instruments for the measurement of direct current amperes and volts. But an important element in the invention is still to be named. It was essential that the glass pen should write without friction, and Thomson effected this by the happy device of electrifying the ink so that the ink and the paper attracted one another, with the result that the siphon was maintained in a constant state of rapid vibration, alternately advancing to the paper to deposit a minute drop of ink and then springing back, but all the time free to follow without friction the movements of the coil in obedience to the electric impulses arriving through the cable. Dynamically the siphon recorder has to satisfy the same conditions as those that determined the design of the mirror galvanometer. It draws on the moving strip of paper a curve of arrival for every one of the successive currents of which the signals are composed.

Here we have (Figs. 7 and 8) a front and side view of the recorder substantially in the form in which it first came into use in 1870. The field magnets MM, between the poles of which the coil S is suspended, have their magnetic circuit completed by a heavy iron trough NN in which they lie. On the table there are specimens of recorder strip showing a succession of alphabets. A very early example of recorder actually No. 2, I understand, is kindly lent by the Eastern Telegraph Company for exhibition to-night, who have also sent an example of the most modern form. To this day the recorder remains in universal use as the standard instrument in submarine telegraphy. It has been simplified by the substitution of permanent field magnets for electromagnets, and by the use of an electromagnetic vibrator for the siphon instead of electrification—changes which were made in later years by Thomson himself.

Thomson was now beginning to reap some reward for his inventions. He had formed, in 1865, a partnership for telegraphic patents with Cromwell Varley and Fleeming Jenkin. Varley's chief contribution was the highly important device of signalling through condensers, and Jenkin was associated with Thomson in the invention of what is known as "curb sending." This is a method of sharpening the signals through a cable by following up each signal-current with a

reversed current of somewhat shorter duration, instead of putting the cable to earth, the effect being to get as it were a quicker emptying of the cable in preparation for the next charge. Much ingenuity was spent in perfecting apparatus for carrying out this principle, but it did

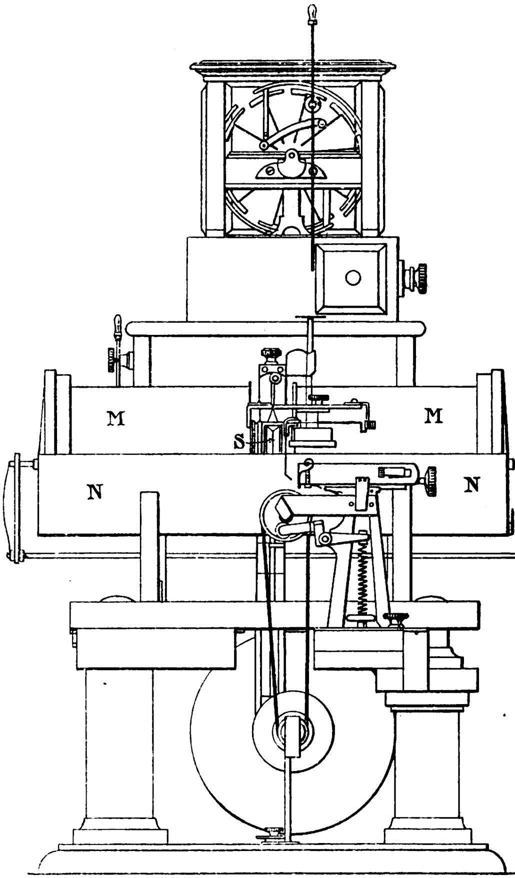


FIG. 7.—Siphon Recorder (Front View).

not come into very extensive use, and substantially the same result is now arrived at by other means.

Besides this triple partnership in patents there was a separate partnership between Thomson and Jenkin which lasted until Jenkin's death, under which they acted as consulting engineers for the construction and laying of submarine cables. Among the cables for which they acted were the Western and Brazilian line, the first section of which was laid in 1873 by the steamship *Hooper*, a ship

specially built for cable-laying with what was for those days a phenomenally large capacity. I recall a voyage of the *Hooper* when in mid-ocean she dropped one of the two blades of her single screw: she completed the round trip to Rio Janeiro and back, including the laying of the cable, on a single blade; and it puzzled us

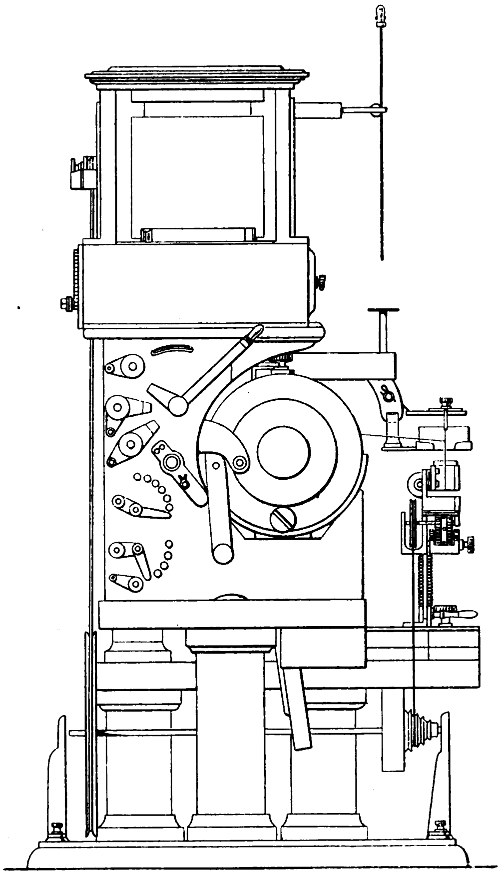


FIG. 8.—Siphon Recorder (Side View).

youngsters to understand how the run, the day after the blade was dropped, was better than any run made before! Sir William Thomson went out in the *Hooper* on her first trip, and at Madeira, where there was some delay through the cable having to be turned over in the tanks to cut out a fault, he met the lady who afterwards became his wife. In teaching her the Morse alphabet the acquaintance ripened fast. Thomson was at that time an ardent advocate of the use of

Morse by occulting lamps and other devices as a means of communicating intelligence at sea. In one of his letters home he says: "We had some admirable lamp signalling several evenings between the *Hooper* and Mr. Blandy's house about 1½ miles distant. The Miss Blandys learnt Morse very well and quickly, and both sent and read long telegrams the first evening they tried it, to the admiration of France and other old telegraphers on board." Those of you who have known Lady Kelvin do not need to be told how happy a chance this meeting proved to be, nor how much he owed, throughout all the remainder of his life, to her understanding sympathy and unceasing solicitude.

Those were days when the testing-room of the cable factory was a better school in which to learn electricity than any laboratory. Practice, which owes so much to science, was just then giving back, in that department of knowledge, as much as she received, or more. The electricity of the workshop had outstripped the electricity of the schools: it had become more scientific than the electricity of the lecture-room and of the text-book. Members of this Institution have no need to be ashamed of the heritage that has come to them from the earlier Association from which this one sprang—the Society of Telegraph Engineers. To the telegraph engineer of the sixties and seventies is due most of the exact measurement and much of the exact thinking which supplies the foundation of the electrical engineering of to-day.

I have spoken of the early association of Thomson with Fleeming Jenkin in telegraph work, in patents, and in the determination of the electrical units. Here are a few reminiscences which have been kindly sent me by Mrs. Fleeming Jenkin:—

"My recollections date from the autumn of 1859, when I first saw him. Fleeming had told me much about him, speaking of him with great affection, but also with awestruck admiration and veneration, so that I pictured to myself Professor Thomson as an aged and severe philosopher and rather dreaded an introduction to him. One evening I was sitting reading by lamplight, when I heard hurried steps coming up the stairs: the door opened and in came a tall, fair-haired young man, who, not waiting to be announced, said with a most radiant smile, 'Where is Fleeming? Are you his wife? I must see him. I am William Thomson.' Then he spoke a few kind words of congratulation on my recent marriage, and I saw for the first time that benevolent bending of his eyes on the person to whom he spoke that always remained, and increased, I think, with the years. But the splendid buoyancy and radiance, which made me say to my husband when he came in later, 'I have had a visit from Professor Apollo,' I never saw again. It was in the following winter that Professor Thomson met with the accident which lamed him for life.

"From that time forward I often saw Professor Thomson. He and Fleeming were experimenting together on submarine telegraphic instruments. As Professor Thomson lived in Glasgow, our house in

London became the place where the experiments were carried on, and our dining-room the workshop. Gradually, as the number of instruments increased, our dining space became smaller, till I seem, remembering, to see Professor Thomson and Fleeming and me dining together hurriedly on a little island in the middle of the room, surrounded by an ever rising tide of galvanometers, coils of wire and mechanism of all sorts. After dinner they used to set to work and work for hours. I used to make coffee and tea and carry it in to them from time to time, and sometimes I was trusted to sit with a watch in my hand and count the seconds between one flitting flash of light and the next on the instrument then in hand.

"I say we dined hurriedly, because Lord Kelvin always did, or seemed to me always to do, everything at topmost speed. When he came, it was always in a hansom cab, in front of which he stood, urging the driver on and guiding him by his pointing stick to our house, the address of which he never could learn though he came thither constantly, and when he went he was whirled away just in time to catch some mysterious train which started for Glasgow at the earliest possible hour in the morning.

"He loved music and would listen to it in a sort of trance of enjoyment. But at this time he would admit none but German music to be music, and used vehemently to attack Italian music, which we admired. It happened, a day or two after such a discussion, that we had an opera box sent us. The piece was Rossini's 'Semiramide.' Professor Thomson arrived to dine and work as usual, but we carried him off to the opera, but did not say what opera was to be given. We were a few minutes late, and as we took our seats Trebelli began her great song. He listened in rapture and at the end said 'Beautiful.' I held the play-bill out to him, pointing to the name of the composer, 'Rossini.' 'Ah!' said he, 'but it *was* beautiful and I was wrong.'

"One more recollection is of a luncheon party at our house, to which he came; a very learned luncheon party; there were three Senior Wranglers present at it. The talk turned, not unnaturally, on scientific matters; Sir William to illustrate what he said, and to prove that if a tumbler full of water were turned upside down in a certain way, the water would not come out, took a tumbler, filled it, turned it upside down—and all the water poured down on to the table. Murmuring 'Some error,' he filled it again, turned it upside down again, and down came the water again, so that the table was all aswim. Terribly sorry and begging pardon in his kindest way, he became flurried, and dropped the tumbler, which broke in pieces. He was inconsolable and insisted on driving round by a shop on his way to the station to buy me a tumbler in place of the broken one. In the greatest hurry, and in spite of all we could say, he caught up the broken pieces to match them and drove off. Soon he came back in triumph, waving a tumbler from the cab window. Fleeming ran out to receive it: Sir William drove off: Fleeming brought in the tumbler: it did not match!

"And then the last time I saw him, not many months before his death, when his kindness and courtesy were, if possible, more beautiful than ever: when he insisted on giving me his arm and bringing me out to the carriage I was in, though he was so weak and worn with pain and age."

II.

It is time now to turn to Lord Kelvin's work in Navigation. He loved the sea. "I am a sailor at heart," he said of himself, and for many years he delighted to escape to his yacht, the *Lalla Rookh*, not indeed to take holiday as other men understand it, but to find seclusion for scientific work. In all that concerned the art of the navigator he took a keen interest. And this with him meant an impulse to improve the art. *Nihil tetigit quod non ornavit.* Taking the two oldest aids to navigation, the compass and the sounding-line, he revolutionised them both. Where most men would have thought there was nothing left for invention to do he found much. He has earned profound gratitude for appliances which add immeasurably to the security of all who go to sea. He has been called the best friend the sailor ever had; and it is said that a blue-jacket was once overheard to remark, "I don't know who this Thomson may be, but every sailor ought to pray for him every night."

It was about 1873 that he began to study the compass seriously, partly because he had undertaken to write an article on it for *Good Words*, and partly because he had occasion to prepare, for the Royal Society, a biographical sketch of his friend Archibald Smith, containing an account of Smith's work on the theory of the perturbation of the compass caused by the magnetism of iron ships. Kelvin's first patent for an improved compass was taken out in 1876.

He found the compass full of serious defects. For one thing it was very unsteady—that is to say, it was liable to be set swinging through a large angle when the ship rolled. Sometimes an attempt was made to reduce this unsteadiness by introducing friction at the pivot which, in a way, made matters worse by causing the compass to stick, pointing in a wrong direction. Under a mistaken idea of what would lead to steadiness, the card was made heavy and the needles long; and the long needles made it impossible to correct the compass properly for the magnetism of the ship. This was the most serious defect of all. In iron ships, and especially in ironclads, the compass is at the mercy of disturbing influences which do much to mask the true directive force of the earth's magnetic field. To neutralise these is indispensable: the way to do it, as a matter of theory, had been pointed out, but it was only through the radical changes in construction which we owe to Kelvin that it became possible to carry the process into effect.

He recognised that for this purpose the needles must be short. Further, that for steadiness what was wanted was a long period of horizontal oscillation—in other words, small magnetic moment rela-

tively to the moment of inertia of the card. But, to keep the frictional error down, the weight of the card, including the needles, should be small. So he made the card (Fig. 9) as light as he could get it; a mere aluminium rim tied by silk threads to a small central boss, just as the rim of a bicycle wheel is tied to the nave by wire spokes; and from the silk-thread spokes he hung short pieces of magnetised knitting needle to serve as the magnets. The result was that not only was the total weight very small, but it was nearly all in the rim, where it is most useful for giving moment of inertia and consequent slowness of period. Magnets and all, the card only weighs 180 grains, for a 10-inch size, and yet its period of oscillation is much longer than that of the

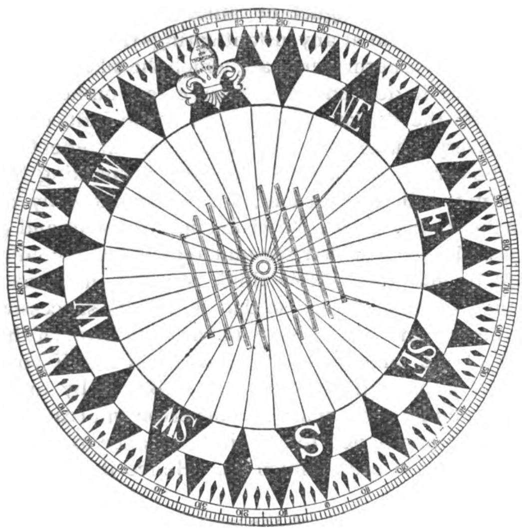


FIG. 9.—Kelvin Compass Card.

old standard compass, while its friction error is less. Its gossamer structure puzzled navigators accustomed to earlier forms. I have been told of Lord Kelvin's once showing it to a committee of admirals who were disposed to say, "Too flimsy; sure to be fragile." His reply was to throw it across the room. It took no harm, and one version of the story says that he threw after it what was then the Admiralty standard card—a vastly heavier structure—with disastrous results.

Another admirable feature of Kelvin's invention was his method of keeping the compass always level and free from pendulum-like oscillation. He hung the bowl, as usual, from gimballs, but with knife-edges instead of the usual round spindles at the trunnions, and under the card he provided a chamber at the bottom of the bowl partly filled with castor-oil. You see this in the glass bowl now on the table. There is a glass partition to separate the place where the compass

card stands from the lower part of the bowl, and in the lower part is the castor-oil. Its function is to damp out any oscillation of the bowl that may tend to be set up by the rolling or pitching of the ship, and it does so by dissipating the energy of such swings. At the same time the knife-edge gimballs leave the compass perfectly free to take up a true level.

Another feature is that the bowl and gimballs as a whole is hung from springs to withstand vibration caused by the action of the screw, or in warships by gun-fire.

Now as to the correction for the magnetism of the ship. Let me indicate very briefly the nature of that problem, and how it is solved.

An iron ship is a great magnet, or rather a great aggregate of many magnets. Her magnetism at any instant springs from two causes. First there is the more or less permanent part, which she takes up to begin with when she is built: it depends to a great extent on how her head lay while she was on the stocks. Then there is the induced part which changes with every change of course: a transient effect due to the induction of the earth's magnetic field. Strictly speaking the induced magnetism is not entirely transient, nor is the other by any means entirely permanent; but the ideal division into transient and permanent is a highly useful one provided we understand the limitations within which it is to be accepted. Now think of what happens when the ship is "swung"—that is, turned so that she heads successively on all points. The permanent magnetism will cause an error of the compass which will be of the same nature as you would find if you placed a compass needle on a fixed pivot, and disturbed it by turning a bar magnet slowly round a vertical axis. This error will reach a maximum twice in the revolution—once to one side and once to the other side—in other words, once in each semicircle. Hence it is called the semicircular error.

The permanent magnetism of the ship need not, and as a rule will not, be simply in the direction of the length. In general it will be inclined both sideways and up and down, and we may regard it as having three components, one fore and aft, one athwart-ships and one vertical. All three components contribute to produce semicircular error, and the semicircular error produced by them is corrected by putting permanent correcting magnets underneath the compass, in the binnacle, which are carefully adjusted, so that they produce, at the compass itself, a horizontal magnetic field which exactly balances there the disturbing horizontal field due to the ship's magnetism. The adjustment is carried out by putting in more or fewer magnetised bars, and placing them at a higher or lower level in the binnacle so that they act more or less strongly on the compass above. One group of the corrector magnets faces fore and aft, and another faces athwartships. The fore and aft magnets are adjusted to correct the error that is found when the ship's head is east or west, the 'thwartship magnets are adjusted to correct the error when the ship's head is north or south.

If the ship remained always on even keel these two sets of horizontal correctors would suffice to correct completely the deviations which are caused by the permanent magnetism of the ship. But when the ship rolls or when she is permanently heeled over to one side another kind of error, called the "heeling error," comes in, which arises from the fact that the ship's magnetism has a vertical component. I am still speaking in the first place of the permanent magnetism of the ship: we shall come to the effects of induced magnetism later. When the ship heels to either side the component that was vertical to begin with becomes inclined, with the result that a new deviating force comes into play. Say, for example, that the ship has been built in England or in any other northern country. The vertical part of the permanent magnetism it has acquired in the building will make the bottom part of the hull have polarity of the kind that attracts the north-pointing end of the needle, while the upper works will, of course, have polarity of the opposite kind. What will be the effect on a compass standing on the upper deck or on the bridge when the ship heels? The polarity of the bottom of the hull will then give the north point of the compass a pull to the side that is tilted up. The heeling error due to this cause will be a maximum if the ship's head is north or south; it will be zero if the ship's head is east or west. In a steamer, unless there has been a displacement of cargo, there is no continued heel to one side, such as you have in a sailing ship when running on a particular tack, but nevertheless it is important to correct the heeling error, for as the ship rolls the effect of heeling error is to give the north point of the compass alternate pulls to port and starboard, which tend to set it swinging.

Hence, in addition to the horizontal magnet bars which act as correctors of the semicircular error, Kelvin put in his binnacle an upright bar or bars also of permanently magnetised steel, the first function of which is to correct the heeling error so far as that is due to the vertical part of the permanent magnetism of the ship. These bars are put directly under the centre of the compass card. They are adjusted by raising or lowering a can which contains them in the middle of the binnacle.

Thus by a combination of three sets of correcting magnets, two horizontal and one vertical, he obtains complete neutralisation of the disturbing effect of the ship's permanent magnetism, both as respects semicircular error in change of the ship's course and heeling error as she heels or rolls. From time to time, if the condition of perfect compensation is to be maintained, the position of these various correctors has to be altered, because of changes which take place in the so-called permanent magnetism of the ship. The navigator has always to be on the look-out for the gradual development of errors from this cause, however perfectly the first adjustment has been carried out.

We have next to consider the effects of induced magnetism. The most important of these arise from the fact that the ship is a long body of magnetisable material turning in a horizontal plane and therefore subject to the inductive influence of the horizontal component of the

earth's magnetic field. Think of what would happen if we were to take a pivoted compass needle, and place it above or below a bar of soft iron, and slowly turn the bar round in a horizontal plane. We are to think of the bar as having no appreciable magnetic hysteresis, so that in every position it is the induced effect only with which we have to do. What will be the nature of the deviation? When the bar points north, and again when it points south, there is no deflection of the needle, for though the magnetism of the bar is then at its strongest, the field due to it is in line with the undisturbed earth field. Also when the bar points east or west there is no deflection, for the bar then

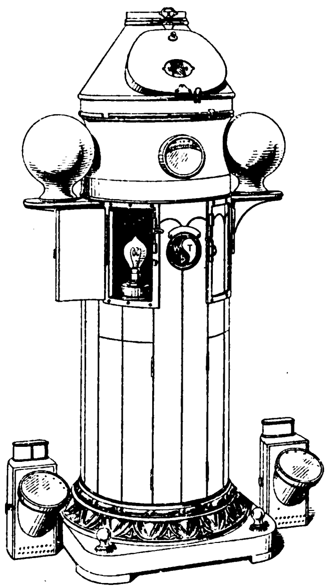


FIG. 10.—Binnacle of Kelvin Compass.

takes up no magnetism. But between these points, namely, when the bar is pointing N.E. S.E., S.W., or N.W., the deflection is at its maximum. So in a ship's compass this error, due to the purely transient magnetism induced by the horizontal component of the earth's field, has its maximum on these four courses, once in each quadrant, and for that reason it is called the quadrantal error.

It is due, as we have seen, to the ship's being a long body, extending fore and aft, and it is corrected by balancing this excess of fore and aft iron by other iron, placed quite near the compass and on either side of it. The two balls which you see on the side of the Kelvin binnacle (Fig. 10) are the correctors for quadrantal error. They are adjusted in the first place by selecting a suitable size of ball, and then placing them nearer to or further from the compass until on swinging the ship the quadrantal

error disappears. The possibility of correcting the quadrantal error in this way had been pointed out by Airy as early as 1840; but with the old form of compass card and needles it could not be done, because of the excessive length and large magnetic moment of the needles. To apply the method to a compass of the old pattern would have needed globes of impracticable size, not a few inches in diameter as these are, but weighing tons. Kelvin, with his short needles on a light card, made it possible to carry out the process and so gave the world for the first time a compass that would point truly to the magnetic north, notwithstanding all the perturbations due to permanent and induced magnetism in the iron of the ship. In Fig. 11 we have a binnacle where the

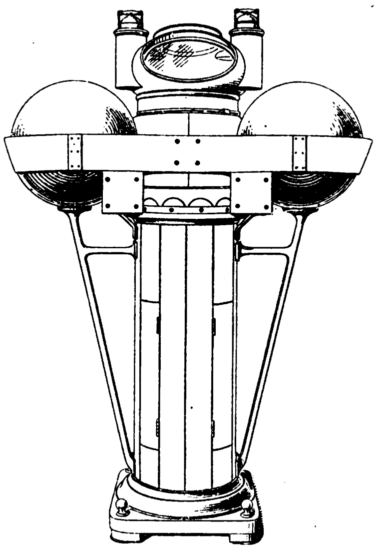


FIG. 11.—Binnacle with large Quadrantal Correctors.

iron balls are comparatively large, for a case where there is much quadrantal error to correct.

One more of the disturbing causes remains to be mentioned. The vertical component of the earth's field induces magnetism as well as the horizontal component, and gives rise to an additional error of two kinds, namely, a further semicircular error and a further heeling error. These are distinct from the semicircular error and heeling error due to permanent magnetism, and the right way to correct them is to fix a bar of soft iron in a vertical position * near the binnacle, so that the magnetism induced on it will act as a counter-balance. This is the Flinders bar, so called because its use was pointed out by Captain

* That is to say, vertical when the ship is on even keel, or perpendicular to the deck.

Flinders as early as 1801. It has generally to be fixed in front of the binnacle, and in Kelvin's compass it is made in several separate lengths of soft iron, which can be put together to make up a bar giving any necessary amount of correcting effect.

The main function of the Flinders bar is to correct the semicircular error due to induced vertical magnetism. So far as the heeling error is concerned it also helps, but in practice it is found convenient to correct a part of the heeling error due to induced magnetism by means of the same kind of permanent magnet correctors as I have

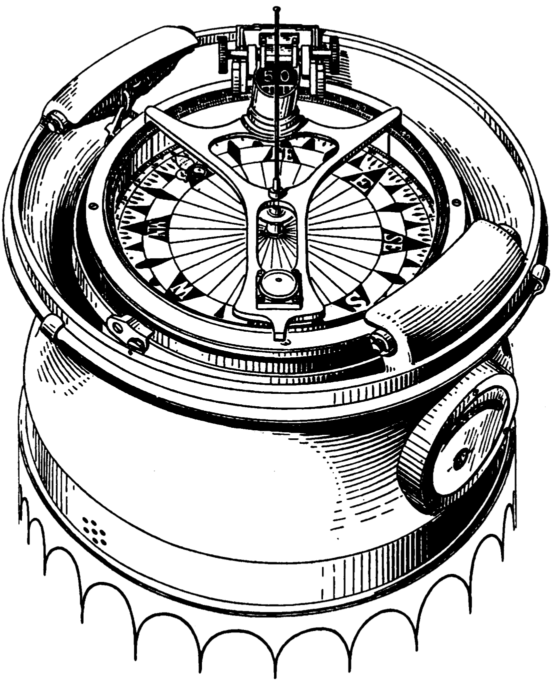


FIG. 12.—Kelvin Compass with Azimuth Mirror.

already described in speaking of the heeling error due to permanent magnetism, namely, vertical magnet bars placed in a can in the binnacle directly under the centre of the compass card. The number or height of these bars has therefore to be altered from time to time, as the ship moves to regions where the vertical force is different.

When the heeling error is fully corrected we escape one cause of the unsteadiness which a compass shows when a ship rolls, for we escape the magnetic cause of oscillation, namely, the alternate magnetic pull to port and starboard. But a purely dynamical cause of unsteadiness necessarily remains, arising from the fact that the

point of suspension of a compass card must be placed some way from the centre of gravity to hold the card level against the dipping action of the earth's magnetic field. Consequently every roll to either side applies a mechanical couple tending to set up oscillation, and if the period of the roll were the same, or nearly the same, as the period of oscillation of the card, the disturbance would become so great as to make steering by compass impossible. It was to secure steadiness in this sense that Kelvin strove to give his compass card a long period of oscillation, recognising that the right way to obtain steadiness was to make the period much longer than the period of the slowest rolling motion liable to occur in a ship, at the same time keeping the friction as small as possible. The problem of securing a steady frictionless compass was a problem where, as in the invention of the mirror galvanometer, his genius for practical dynamics guided him to the right solution. In the case of the compass it was rendered difficult by the fact that other conditions, apparently antagonistic, had at the same time to be satisfied in order that the correction of magnetic errors might be completely carried out.

As an adjunct to the improved compass he invented the azimuth mirror, an apparatus which, standing on the top of the bowl, allows the bearings of distant objects to be readily taken by sighting over the tops of the correcting globes. The azimuth mirror is seen standing on the top of the compass in Fig. 12. It slides on the top so as to turn in any direction. The optical arrangement by which the distant object and its bearing on the compass card are simultaneously brought into view will be apparent on referring to Fig 13.

All this was the work of several years. His first article on Terrestrial magnetism and the mariner's compass appeared in *Good Words* in 1874; it was an introductory historical sketch, and the second article did not appear till 1879. During these five years he had, as he said, been learning his subject. The problem of obtaining a compass which would be steadier at sea, and at the same time better adapted for the perfect correction of the errors due to the iron of the ship, forced itself on him when he tried to write the article. "When there seemed a possibility," he said, "of finding a compass which should fulfil the conditions of the problem, I felt it impossible complacently to describe compasses which perform their duty ill, or less well than might be, through not fulfilling these conditions." Hence what he had at first thought would be the "pleasant and easy task" of describing an instrument familiar to navigators for six hundred years took five years to accomplish, and before it was completed he had given to the compass a character of precision it never possessed before.

He also invented the *Deflector,* an instrument for testing the adjustment of the various correcting magnets. By means of the deflector the compass error can be corrected when sights are not available, either of the sun or of marks ashore, to determine the true course in each position as the ship is being swung. The principle on which the deflector works is that when the correcting magnets are

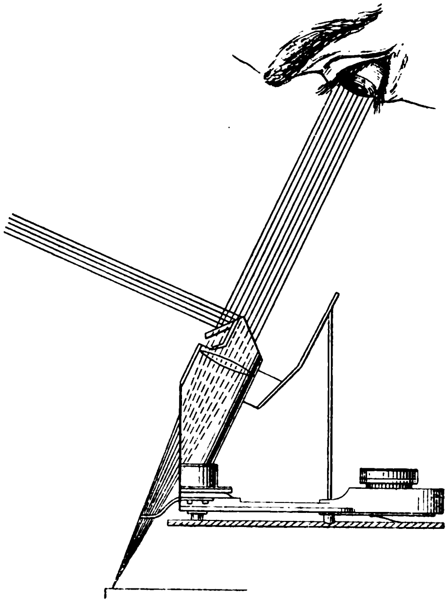


FIG. 13.—Illustrating the action of the Azimuth Mirror.

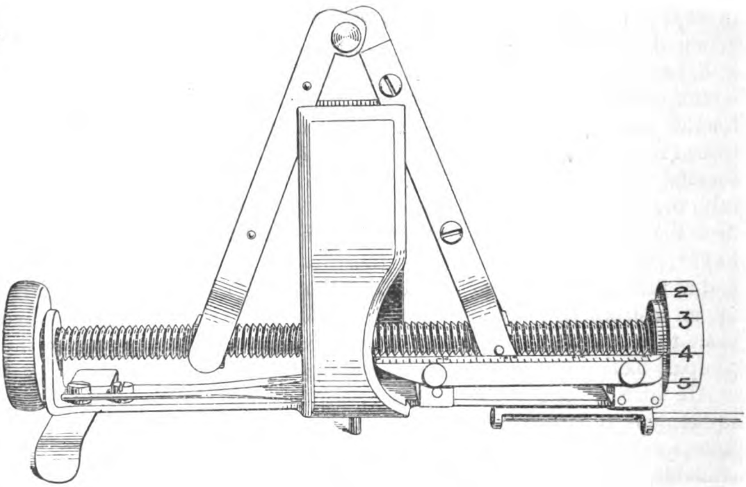


FIG. 14.—Deflector.

rightly set the magnetic field acting on the compass is the same (at any one place) in whatever direction the ship's head points.

The deflector (Fig. 14) is a pair of magnets arranged somewhat like the legs of a pair of compasses. By opening the legs their power to deflect the compass needle is increased. This instrument is placed on the glass top of the compass bowl, and the legs are opened until some definite large angle of deflection is observed, say 85°. Then it is removed; the ship's head is turned to another course, and the deflector is replaced. If the same opening of the legs just suffices to give the same deflection on this second course, the directing field on both courses is the same. The process is repeated for other courses, and if differences are found the correcting magnets are adjusted until they disappear.

Lord Kelvin also at a later date designed an instrument for measuring the vertical magnetic force to facilitate the compass

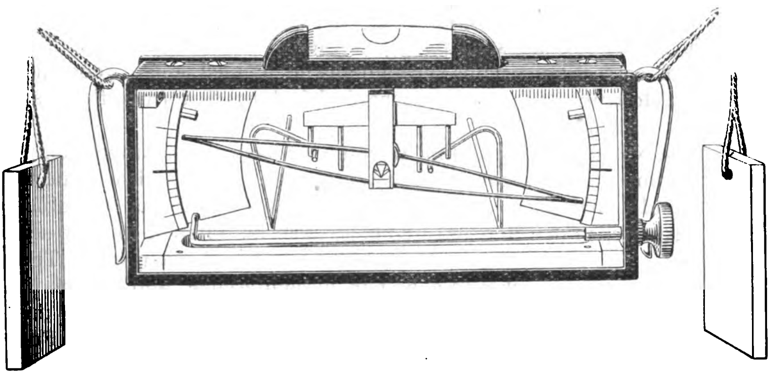


FIG. 15.—Vertical Force Instrument.

adjuster's correction of the heeling error by giving the means of comparing the vertical component of the earth's field on shore with its value at the compass. It was as recently as 1906 that he brought out the latest form of this apparatus (Fig. 15).

The evolution of the Kelvin compass, in its main features, took about five years; but a longer task lay before the inventor in overcoming the professional conservatism of sailors, the objections of the so-called practical man, active hostility in some quarters, and the passive resistance of official inertia. Gradually the compass came to be used in merchant vessels of the best appointed class. Enlightened navigators such as Captain Lecky, the author of the well-known "Wrinkles," became its enthusiastic advocate. Foreign Admiralties took it up, and in our own service individual officers were quick to see its merits. Captain Fisher, now Admiral of the Fleet Lord Fisher, was warm in its praise, after observing its behaviour in ships under his command, first in the *Northampton* in rough weather and afterwards in

the *Inflexible* during the firing of heavy guns in the bombardment of Alexandria. That was in 1882. But it was not until November, 1889, that the Superintendent of the Compass Department of the Admiralty was in a position to inform Lord Kelvin that his 10-inch compass was to be adopted as the standard compass for the Navy. This was twelve years after the date of his patent, and more than eleven years after he had laid the invention formally before the First Lord. The way of the inventor, like that of the transgressor, may still be hard, but I trust it is not so hard now as it was then. One does not care to dwell on the spectacle of a Kelvin spending his strength in disheartening effort as the sea beats against a cliff. It is painful to read the correspondence and discussions of those weary years. One does it with increased admiration of the infinite patience which at last secured to us the benefits of his practical genius.

The use of the Kelvin compass may now be said to be universal, except that in the Navy a modified form, due to Captain Chetwynd, with a card immersed in liquid, is taking the place of the Kelvin dry card in the newer ships, as being steadier still under gun-fire. The system of correction remains substantially unchanged, and the compass continues to embody the same mechanical features as formed the basis of Kelvin's invention.

In the Navigational Sounding Machine we have another invention of first-rate importance, second only to the compass in practical value to sailors, and remarkable for its extreme simplicity. It was his cable-laying experience that first led Kelvin to take an interest in deep-sea sounding. The process, as then carried out, was a laborious one. The line was a rope, an inch and a half in circumference, and though it carried a very heavy sinker the resistance to its motion through the water was so great that it took a long time to reach the bottom. For the same reason the ship had to be stopped while the line ran out, and, except in shallow water, while it was being heaved in. Many hands were needed, and much time was spent in making a cast. Hence it came about that the operation of sounding, beyond the use of the hand-lead in quite shallow water, was but little resorted to as an aid to navigation, notwithstanding the importance of the indications it could give in such cases as when a ship was approaching land in a fog or in circumstances which made the exact position uncertain, when the depth might be anything up to, say, one or two hundred fathoms.

I have spoken already of Thomson's study of the forces acting on a cable during its submersion. Applying these principles to the sounding-line, he recognised that to make the line slip down quickly, it should have the smallest possible and the smoothest possible surface, and this led him to use a single wire of steel—the steel of high tensile strength used in pianofortes. In 1872 he demonstrated the practicability of using wire, by taking a sounding and finding bottom at 2,700 fathoms in the Bay of Biscay, with a 30-lb. sinker and a single wire of No. 22 gauge. He soon devised a suitable drum and winding-in wheel for deep-sea use, and from this was developed later a compact form of navigational

sounding machine by which flying soundings are taken without stopping the ship.

In a flying sounding the wire streams out behind, taking an oblique course to the bottom, and the length of wire that runs out is greatly in excess of the depth. To read the depth directly, Thomson invented several forms of depth gauge, the simplest of which is a long narrow glass tube, closed at the top, and coated inside with chromate of silver or some other chemical which is discoloured by the action of sea-water. This tube is put in a protecting case which is attached near the sinker,

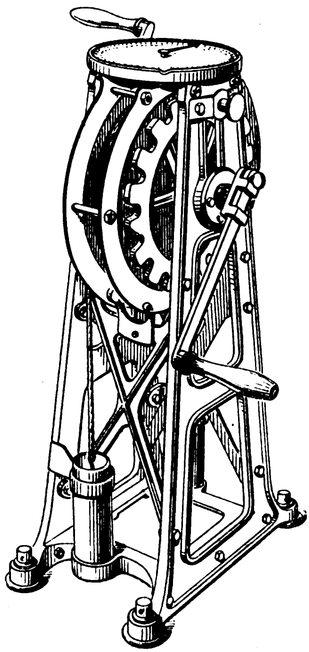


FIG. 16.—Navigational Sounding Machine, Navy Pattern.

and as it descends the increased pressure forces the sea-water up into it, compressing the air, and indicating the depth by the height to which the chemical lining is discoloured. Accordingly the depth is read off by laying the tube against a scale when the line is again drawn on board.

This machine (Fig. 16) has become a standard navigational appliance. The length of wire in common use is 300 fathoms. A strand of seven fine steel wires, which gives greater flexibility, is now substituted for the single wire. It runs out under a regulated tension, supplied by a rope brake which retards the rotation of the drum on which the wire is wound. When the sinker touches bottom the tension is at once seen to slacken, or rather felt to slacken by a sailor who keeps a little

rod of wood lightly pressed against the wire while it runs out ; the drum is stopped, and the wire is slowly wound in again by hand, or in the latest naval type by electric motor. Lord Kelvin's latest improvements in the machine were made only a year or so before his death : they were, in fact, his last serious inventive work. They include a large horizontal dial which will be seen in the figure at the top, for reading the number of fathoms of wire out, and with this it is often practicable to tell the depth very closely without resorting to a depth gauge at all. For in the modern machine the action is so uniform that, at any given speed of ship, a definite relation holds between the depth and the length of wire out, and by finding this relation once for all a table can be prepared by which the speed is known, and so when the length of wire out is observed the depth

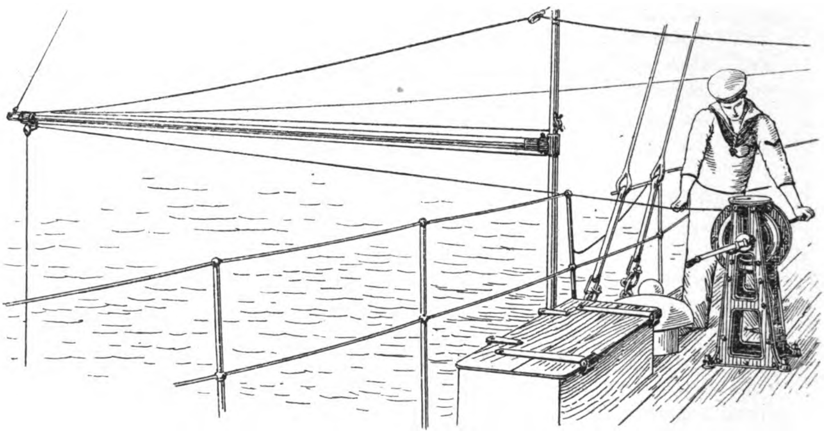


FIG. 17 —Taking a Sounding from the Bridge.

may be at once inferred. This system is now in regular use in the Navy. A pair of the Kelvin machines stand on the bridge ; the wire runs out along a boom at either side and over an ingeniously designed pulley or fair-lead (Fig. 17) ; whenever soundings are wanted, they can be taken systematically and in quick succession while the ship proceeds at undiminished speed, and the depth is called out for the information of the navigating officer almost as soon as the wire has stopped running out. Alike in the Navy and the merchant service there is no difficulty in making it a matter of routine to keep the sounding machines going incessantly, when near shore or within, say, a hundred fathoms in thick weather.

Time presses : but I must say a few words about another of Kelvin's services to navigation ; his advocacy of what is now called the *Position Line* in the working out of a navigator's "sights." The ordinary "sight" of the sun or of a star is an observation of the altitude above the horizon

at a known instant of Greenwich time. The navigator takes its altitude by his sextant, and at the same instant reads the Greenwich time by his chronometer. What is the information that such a sight furnishes as to the position of the ship? In the first place, from the observed Greenwich time you know that the sun or star was at that instant vertically over a particular spot on the earth's surface, and in the second place, from the observed altitude you know that the ship was a certain distance from that spot. If the altitude had been 90° the ship would have been just at the spot in question; and being less than 90° she must be some way off—somewhere, in fact, on a circle from every point of which the altitude would have the observed value. All the sight tells you, then, is that the ship is somewhere on the circumference of a certain circle, and practically you are concerned with a little bit of the circumference—a short arc in the neighbourhood where you know that the ship happens to be. On the chart this little arc of the circle may be represented with sufficient accuracy as a straight line. This line is called the Position Line for the given sight, and once the position line is drawn on the chart you have a complete representation of all that the sight is able to tell: what it tells is simply that the ship is somewhere on that line. To get the actual position an independent second observation is required: it may be the bearing of an object on land, or it may be another observation of the altitude of a heavenly body, and if you draw the position line for that also the intersection of the two will fix the place of the ship. Both sights may be of the same body—the sun, for instance—taken at different times, and if the ship has been moving in the interval, the first line must be shifted parallel to itself through a distance representing the run of the ship, before the intersection of the two lines is used to fix the position at the time when the second sight is taken.

It is to an American navigator named Sumner that the honour belongs of first pointing out the desirability of drawing, for every sight, the corresponding position line, and of showing how the line might practically be found. But Sumner's method was somewhat tedious and the advantages of the Sumner line or position line were but little understood. Kelvin realised them, and saw too how the process of drawing the line might be greatly simplified. For this purpose he published his *Tables for Facilitating Sumner's Method at Sea*, which immensely reduced the labour of calculation, and incidentally supplied the navigator, in the working out of the sight, with a piece of information of great value, namely, the true bearing of the sun or star. Its value is this, that by comparing the true bearing with the bearing taken by compass at the same time as the sight, a test of the accuracy of the compass is incidentally obtained.

The particular method of mathematical solution introduced by Kelvin did not come into extensive use, and since then other ways of drawing the position line have been devised which are generally preferred. But the main point is that navigators have now become

familiar with the important truth which Kelvin insistently preached, that for every sight the line should be independently drawn. The position line has come widely into use. It is accepted as the right means of representing the result of each separate observation. It expresses the truth, the whole truth, and nothing but the truth, of what each sight tells as to the position of the ship. I believe it is in great part owing to Kelvin that this revolution in the practical art of nautical astronomy has come about.

In this connection I must tell a little story. His *Tables for Facilitating Sumner's Method* on their publication in 1876 were reviewed in *Nature* very favourably, but were subsequently attacked in that journal by the Astronomer Royal, the late Sir George Airy, then an old man. The criticism was based on a misapprehension of the function of the position line, which it is difficult now to understand. I had helped in getting out the tables, and was indignant at a criticism which might do much harm and was essentially invalid. I telegraphed to Kelvin asking his permission to publish a reply. He promptly telegraphed: "Yes, by all means answer in your own name, but don't hit too hard. Remember he is four times as old as you."

We must pass over with the barest mention Kelvin's advocacy of periodic occultations as a means of distinguishing lights at sea, the proposal that fixed lights should be identified by making each light signal some letter of the Morse alphabet in a group of short and longer periods of darkness. Nor can anything be said of the assistance he twice gave to the Admiralty by serving on committees which had to advise as to the selection of types of battleships and cruisers, first in 1871 after the loss of the *Captain*, and again in 1904–5—when the design of the *Dreadnought* was under consideration. For the time that remains must be used to speak of his work in connection with the tides.

It was at Kelvin's instigation that the British Association formed a Committee in 1867 to investigate tidal phenomena by a method of harmonic analysis introduced by him. Writing to Helmholtz in that year he speaks of having spent many a day on the study of tides on board the *Great Eastern* when waiting for weather or making passages. Members of the Institution of Electrical Engineers are acquainted with the harmonic analysis of Fourier, by which any periodically recurring quantity can be represented as the sum of a series of terms with frequencies which are multiples of the frequency with which the quantity itself recurs. But in Kelvin's analysis of the tides the constituent terms are selected, not as a simple Fourier series, but with reference to the various physically recurring influences which go to build up the resultant tide. The actual tide is treated as the resultant of a group of tides, each due to a physical cause having a definite period of its own, determined by reference to the cause to which each constituent tide is due, in the motions of the moon and sun. Thus there is, in the first place, due to the moon, the lunar semidiurnal tide, the chief of all the constituent tides, whose period is half a mean lunar day. Then there

is the solar semidiurnal tide, whose period is half a mean solar day. Then there are also diurnal tides due to the fact that the sun and moon have declination—that is to say, that they are not in the plane of the equator, and there are long period tides due to the changes of declination which both these bodies undergo—a fortnightly lunar declinational tide, and a semi-annual solar declinational tide. Further complications arise from the ellipticity of the moon's orbit round the earth, and of the earth's orbit round the sun. These various causes produce inequalities which may be treated as effects got by compounding tides of nearly equal period, corresponding to the beats in an imperfect harmony Finally, in a restricted tidal channel there is a distortion in the form of the tidal wave which is dealt with, in the analysis, by introducing the higher harmonic terms of a Fourier series in respect of one or more of the chief constituent tides.

The practical utility of the whole process lies in this, that it enables the behaviour of the tide at any port to be predicted with great exactness. After observations of the tides have been made for a sufficiently long time, either by systematic measurements of the water-level from hour to hour, or by means of a self-recording tide-gauge, the analysis can be applied to calculate the phases and amplitudes of the constituent tides, and once that is done, it becomes possible, as a mere matter of computing, to work out the future tides for the port.

To facilitate this process Kelvin invented in the first place a mechanical analyser, for getting the constants of the constituent tides out of the recorded readings of tide-gauges at the port; but it has been found in practice better to carry out this part of the work without mechanical aid, namely, by measurement and computation. In the second place he invented a mechanical tide predicter which carries out the subsequent part of the operation, giving a very complete automatic synthesis of the constituent effects, drawing a curve, in fact, which shows for a whole year, or longer, the future behaviour of the sea-level at any port for which the constants of the constituent tides have been determined. This machine is now in regular use, at the National Physical Laboratory, for working out the future tides for Indian ports, and the results of its calculations are published in two annual volumes which give full particulars of the future tides for all the chief ports of the Indian Ocean from the Red Sea to the coast of Burmah, from Suez to Port Blair. Thanks to the kindness of Dr. Glazebrook, I am able to show you one of the curves drawn by it—a curve reeled off in an hour or two, which shows the complete tide at a particular port as predicted for half a year—namely, the tide for Aden, for February–July, 1907, and also a part of the curve for 1912.

To get a sufficiently close agreement between prophecy and fact the machine includes twenty-four constituent terms in this mechanical summation of tidal effects. It compounds in the movement of its tracing-pen that number of simple harmonic motions by means of wheels geared so that in their relative frequencies of rotation they correspond to the frequency of the various constituent tides, and the

motions taken from them are adjusted as to amplitude and phase to suit the known constants of the port for which the prediction is being made. The pen is attached to a wire which passes from a fixed point over a succession of pulleys, each of which is caused to rise and fall with the appropriate simple harmonic motion, and the aggregate effect is to give it a displacement which represents with great exactness in every characteristic the rise and fall which the water will really undergo. It is right to add that in bringing his tide predicter to a practical form, Lord Kelvin had much assistance from Mr. E. Roberts, who was employed as computer by the British Association Committee, and by whom the calculation of the gearing was carried out. The chief features of the machine will be seen in the slides now exhibited.

In attempting this account of the work of Kelvin in Telegraphy and Navigation, I am embarrassed by its volume and its range. The time has proved far too short for a fitting notice of discoveries and inventions so various, so fundamental, so far-reaching in their practical effects. And yet we have dealt only with a very small part of the whole achievement of a man not less remarkable for sustained industry than for outstanding originality—a man incessant in action and in thought—of whom it may be truly said that there is no department of physics on which he has not left an abiding impress.

I have said nothing to-night of the lofty flights of scientific imagination which are, perhaps, his highest title to fame. But I have said enough to show that Kelvin was no mere philosopher with head in the clouds. He was quick to recognise a real need: quick also to see how the need should be met. He found material for invention in the most commonplace appliances, because his mental habit was in everything to seek for the how and the why and to ask himself in what way the thing might be done better. And he had an infinite faculty of taking pains: of adhering to a purpose till he secured its full accomplishment: of going on from improvement to improvement in pursuit of the more perfect result. And with all this he had a courage and hopefulness that no opposition could damp, that never accepted defeat.

We may apply to him the words which he himself used of Cyrus Field: "He possessed an admirable and unapproachable quality, an attribute of heroes: he never knew when to give in."

Mr. Siemens.

Mr. ALEXANDER SIEMENS: As a friend of long standing of the late Lord Kelvin I have very much appreciated the lecture we have listened to, and I have very great pleasure in proposing: "That a vote of thanks be accorded to Professor Ewing for his Address, and that with his permission the lecture be printed in the *Journal* of the *Proceedings*." It can only be to the advantage of the Institution if this short account of the more immediate connection of Lord Kelvin with electrical engineering is printed, so that everybody may learn how those qualities which Professor Ewing has told us existed in Lord Kelvin lead to the greatest possible results—that you do not know when you are beaten, and that you stick to a thing which you are convinced is right.

Dr. SILVANUS P. THOMPSON: I have the honour, sir, of seconding the motion which Mr. Siemens has made. We could hardly have hoped to hear a lecture on Lord Kelvin's work from one who was able to speak from forty years' experience, because Lord Kelvin lived so long after his early work that most of those who worked with him in the early days are unfortunately no longer alive. Happily Professor Ewing at an early date, when he was little more than a young student, as he himself has told us, became assistant to Lord Kelvin. And so we have had the opportunity of hearing at first hand about those extremely interesting associations of Lord Kelvin with telegraphic and navigational appliances, and of hearing of them from one who worked with him and for him, and who was his confidential assistant in many of his inventions and investigations. I have been particularly delighted to listen to Professor Ewing to-night, for I have had a lesson—and I think we all have had a lesson—in the art of placing before an audience in a marvellously simple and easy way an extremely complicated and recondite subject. I speak of Professor Ewing's explanation to us of the deviations of the compass and the means taken to correct them. If for nothing else than this we have had a very good success in the Kelvin lecture to-night. So that we have now a double duty to pay to Professor Ewing in thanking him not only for his delightful series of personal reminiscences and a first-hand account of Lord Kelvin's work in several directions, but also for his masterly explanation of the theory of the corrections of the compass. I have very great pleasure in seconding the motion.

Dr. Silvanus Thompson.

The PRESIDENT: It is now my duty to formally put to you that we pass a very hearty vote of thanks to Professor Ewing for his lecture.

The President.

The resolution of thanks was carried with acclamation.

The meeting adjourned at 9.50 p.m.

Proceedings of the Five Hundred and First Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, January 27, 1910—Dr. GISBERT KAPP, President, in the chair.

The minutes of the Ordinary General Meeting, held on Thursday, January 13, 1910, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was announced as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members :—

Frank Ayton.	Wm. Phillips.
Francis H. Francis.	Alex. Rothert.
Geo. Wm. O. Howe.	Carl W. V. Schaefer.
C. H. McCarthy-Jones.	John T. Taylor.

From the class of Associates to that of Associate Members :—

Alfred G. Jackson.	John Wm. Meyer.

Christopher O. Milton.

From the class of Students to that of Associate Members :—

Arthur Hatfield Acres.	Horace Wm. Holt.
Herbert Bamford.	Wm. C. C. Langdon.
Wynne D. Baxter.	Thos. Mitchell.
Chas. R. Bland.	Brian H. Morphy.
Gerald S. C. Bodkin.	Stanley R. Mullard.
Hubert C. Bullman.	John N. Nayler.
Purushottam G. Dani.	Arthur C. Pesterre.
Walter H. St. Davies.	Herbert S. Plymen.
Geo. S. Dearling.	F. R. C. Rouse.
Hugh N. Dutton.	Alban C. Whish.
Cecil C. A. Hardie.	Arthur H. Wilson.

Donations to the *Library* were announced as having been received since the last meeting from Dr. H. Borns, Professor H. T. Davidge, W. A. Del Mar ,The Engineering Standards Committee, Professor G. C. Foster, Bela Gati, Professor G. W. O. Howe, Dr. A. E. Kennelly, Major W. A. J. O'Meara, The Physikalisch-Technische Reichsanstalt, E. & F. N. Spon, Ltd., Professor S. P. Thompson ; to the *Building Fund* from Major P. Cardew, H. C. Channon, A. D. Constable, Dr. C. V. Drysdale, S. Z. de Ferranti, J. F. Henderson, D. Henriques, H. Hirst, Sir H. B. Jackson, A. E. Levin, G. C. Lloyd, A. W. Makovski, W. M. Mordey, Professor J. T. Morris, F. H. Nicholson, A. P. Pyne, W. R. Rawlings, S. R. Roget, J. H. Rosenthal, J. F. C. Snell, M. Solomon, A. Stroh, Sir J. Swan, T. C. T. Walrond, H. W. Young ; and to the *Benevolent Fund* from G. Allom, A. H. Bishop, I. Braby, A. C. Brown, G. B. Byng, M. S. Chambers, R. A. Chattock, W. C. Clinton, P. R. Cobb, A. Denny, J. L. Devonshire, B. M. Drake, Dr. C. V. Drysdale, W. Duddell, K. Edgcumbe, E. Garcke, Dr. R. T. Glazebrook, R. K. Gray, J. S. Highfield, H. Hirst, S. H. Holden, H. A. Irvine, H. W. Kolle, E. de M. Malan, Sir H. C. Mance, E. Manville, W. Mead, C. H. Merz, W. H. Patchell, C. C. Paterson, Sir W. H. Preece, S. R. Roget, S. G. C. Russell, W. H. Scott, A. Siemens, F. Smith, J. F. C. Snell, A. Stroh, J. H. Tonge, T. C. T. Walrond, H. W. L. Ward, J. G. Wilson, R. P. Wilson, C. H. Wordingham, to whom the thanks of the Institution were duly accorded.

The following paper was read and discussed: "Equitable Charges for Tramway Supply," by H. E. Yerbury, Member (see p. 576).

EQUITABLE CHARGES FOR TRAMWAY SUPPLY.

By H. E. YERBURY, Member.

(*Paper received from the* LEEDS LOCAL SECTION *December* 3, 1909. *Read in London on January* 27, *at Sheffield on January* 26, *at Manchester on January* 25, *at Glasgow on February* 8, *and at Birmingham on February* 16, 1910.)

At the present time there appear to be very divergent views and opinions expressed by electric supply and tramway authorities as to the basis of charge for electrical energy for traction purposes, and in many cities and towns tramway managers are agitating for a reduction in the price of traction units, and in the author's opinion the time has arrived when a fair and reasonable computation should be made, which would be applicable in all cases between supply authorities and tramway undertakings. The average price now charged to tramway departments by the sixty-five towns in Great Britain having combined lighting and tramway generating stations—as set out in Tables I., II., III., IV., and V.—is 1·377d. per unit, the maximum price being about 2d. per unit, and minimum price 0·93d. per unit. Considering the low price now being charged by electric supply departments for heating and general power purposes, it seems at first sight strange that a much higher price is invariably charged to tramway departments, notwithstanding the load factor and number of units per annum comparing very favourably with any commercial enterprise; and the object of this paper is an attempt to put forward a scheme which may be considered equitable, with the hope that a useful discussion will be elicited.

FIXED CHARGES AND RUNNING COSTS.

A much debated subject in the early days of electric traction was whether it was advisable to take power from a station originally designed for lighting and domestic purposes or whether it would be more economical to build and equip a separate station. The question cannot well be answered without studying local conditions, still we find the price charged to tramway departments by authorities owning combined stations amounts to considerably more than the total costs in separate tramway power stations, and the question arises, Why is this? It is universally admitted that the price at which any commodity can be sold is determined firstly by its entire cost of production, and secondly by the number or quantity sold. It may further be expressed that the price of manufacturing any

Table I.

Traction and Lighting Stations Combined. Local Authority.

(1908–1909.)

Locality.	Price: Pence per Unit. Lighting.	Price: Pence per Unit. Power.	Price: Pence per Unit. Traction.	Load Factor.	Remarks.
			Corptn.	Per cent.	
Aberdeen ...	M.D. 5½ (1 hr.)–1½ after	M.D. 2½ (1 or ½ hr.)–1	1·17 (*b*)*	18·46	* 2¼ to Suburban Tramways Company.
Accrington ...	4 with discount	3 and 1 discount	1·25	12·11	
Ashton	3½ to 2½*	1½ to 0·9	1·28	21·07	* 2 rate ... $\underbrace{\text{11·0–4·30}}_{1}$ (P.M. P.M.) ... $\underbrace{\text{4·30–11·0}}_{3\frac{1}{2}\text{ to }2\frac{1}{2}}$ (P.M. P.M.).
Ayr	3½	2 to 1½	1·26 (*b*)	19·72	
Barking	4	2½ to 1	1·50	20·99	
Belfast	M.D. 5½ (1 hr.)–1¾, or 3¾	2¼ to 1	0·57 (*a*)*	21·6	* Tramways Committee pay capital expenditure on plant and cables.
Birmingham ...	5–3½, all day 3–2	Large. 2–1·07, or 1–0·7	1·27 (*c*)	21·5	
Blackburn ...	M.D. 6 (1 hr.)–3, 4–5 per cent. discount	6,000 u.p.a. 1½ 44,000 (next) 1 150,000 ,, 0·75 300,000 ,, 0·55 500,000 ,, 0·45	1·40 (*b*)	19·72	

(*a*) Power supply, exclusive of capital charges.
(*b*) Power supply and capital charges on generating plant.
(*c*) Power supply and capital charges on generating plant and tramway feeders.

TABLE I. (*continued*).

Traction and Lighting Stations Combined. Local Authority.

(1908–1909.)

Locality.	Price: Pence per Unit. Lighting.	Price: Pence per Unit. Power.	Price: Pence per Unit. Traction.	Load Factor.	Remarks.
Blackpool ...	M.D. 6 (1 hr.)–2, or 5	3 to 1, heating, 1	1·79 (*c*)	13·39	
Bolton	M.D. $3\frac{1}{2}$ (3 hrs.)–1, or $3\frac{1}{2}$*	1,000 units, 2* after, 1	1·10 (*b*)	27·35	* Less 10 per cent. discount.
Bradford ..	M.D. 7–1 (1 hr. for half-year), or 4	2 to $\frac{3}{4}$	1·14 (*c*)	28·27	Lighting, $2\frac{1}{2}$ per cent. discount. Power, $2\frac{1}{2}$ to 30 per cent. discount. Coal 9s., $2\frac{1}{2}$ per cent. each 1s. rise or fall.
Brighton ...	M.D. 7 (1 hr.)–1, or 4	—	1·50 (*b*)	19·6	
Burnley	$3\frac{1}{4}$, $2\frac{1}{2}$	$1\frac{3}{4}$ and 1, Contract. $\frac{3}{4}$	1·34 (*c*)	23·61	
Burton	M.D. 6 ($1\frac{1}{2}$ hrs.)–3, or 5	M.D. 3 ($1\frac{1}{2}$ hrs.)–1*	1·37 (*b*)*	17·93	* Or 10,000, 2; after, $1\frac{1}{4}$; also 1 to $\frac{3}{4}$ restricted hours.
Bury	4, $3\frac{1}{2}$, 3	2 (1st hr.)–1, $\frac{3}{4}$	1·10	20·5	
Chester	$3\frac{1}{2}$	$1\frac{1}{2}$ to 1 discount to large consumers	1·59 (*d*)	16·08	
Chesterfield ...	M.D.* 6 (1 hr.)–3, or 4	$1\frac{1}{2}$, $1\frac{1}{4}$, 1	1·25 (*b*)	13·94	* Less 10 per cent.
Colchester ...	5–$3\frac{1}{2}$	4 to 1	1·50	17·75	War Office, $3\frac{1}{2}$.
Croydon	M.D. 7–$1\frac{1}{2}$, 5	$2\frac{1}{2}$	1·78 (*b*)	20·60	Time switch, $1\frac{1}{2}$; 5 over-peak.
Darlington ...	$3\frac{1}{2}$	$1\frac{1}{2}$ to $\frac{3}{4}$*	1·12 (*b*)	17·42	* Under 500 per quarter, $1\frac{1}{2}$. Next 1,000 " $1\frac{1}{4}$. " 5,000 " 1; over, $\frac{3}{4}$.

Darwen	4½	2	1·69 (*b*)	12·67	
Derby	M.D. 6 (1 hr.)–2½ or 4½, 3½	3 1st 18 hrs. 2 2nd " 1 after, or 1 flat*	1·5 (*b*)	19·0	* Heating, 1¼.
Doncaster ...	1st hr., 2nd hr. (M.D.) 5 4½ 3	2	1·5 (*d*)	14·20	
Dundee	3½–2, sliding scale	2½ sliding scale	1·25	18·82	
East Ham ...	M.D. 5 (1 hr.)–2, 3½	2 and 1½	1·50 (*b*)	23·71	
Exeter	5	2½	1·75 (*b*)	15·5	
Gloucester ...	100 hrs. per quarter 6–2 after, or 4	1st 200, 2 next 1,000, 1½ " 10,000, 1¼ rest, 1⅛	1·00 (*b*)	15·89	
Halifax	4 to 3	2 to ⅞ Heat, 2–5 per cent. discount	1·06 (*c*)	20·98	
Ilford	M.D. 6 (1 hr.) to 1, or 3½	M.D. 2 (100 hrs. per quarter)– 1 after	1·13 (*b*)	21·68	
Ipswich	4	2 and 1½	1·50 (*b*)	20·34	
Keighley ...	4½ to 4	2 to 1	1·75 (*b*)	18·13	
Kilmarnock ...	4½, with discount	2, with discount	1·25 (*b*)	14·9	
Kirkcaldy ...	4½ to 3	2¼ to ¾	1·12 (*c*)	19·5	
Lancaster ...	4½ less 5 per cent.	2½ to 1½ less 20 per cent.	1·70 (*b*)	12·42	Over 15s. per annum, meters free.
Leith	3½	1½	1·25 (*b*)	19·57	
Leyton	M.D. 5 (1½ hrs.)–2, or 4	M.D. 3 (1 hr.)–1 or 1½	1·25 (*b*)	22·45	
Lincoln	M.D. 5 (1 hr.)–2½, or 4½	50 units per quarter, 2½ 75 " " " 2 over, down to 1	1·25 (*b*)	18·06	5,000 or above in 1 year, M.D. 6–2.

(*b*) Power supply and capital charges on generating plant.
(*c*) Power supply and capital charges on generating plant and tramway feeders.
(*d*) Power supply and capital charges on generating plant and maintenance of overhead equipment.

TABLE I. (*continued*).

Traction and Lighting Stations Combined. Local Authority.

(1908–1909.)

Locality.	Price: Pence per Unit.			Load Factor.	Remarks.
	Lighting.	Power.	Traction.		
Liverpool ...	3,000 10,000 Over per quarter. 3½ 3 2½	2, 1½, 1 as lighting	1·12 (*c*)	22·75	
Lowestoft ...	5½	2,000 Above 2 1	2·13 (*d*)	15·67	
Maidstone ...	M.D. 7 (1 hr.)–2, 4	2–1	1·67 (*b*)	21·6	
Manchester ...	£7 per k.w. M.D. per annum and 1½ per unit*	1⅞ to 1 scale, or 25s. per quarter per E.H.P.	1·04 (*c*)	L. and P. 22·2 % Traction. 32·7	* Or 3¾ flat rate.
Nelson	1,000 units ... 4 3,000 „ ... 3¾ 5,000 „ ... 3½ 8,000 „ ... 3¼ over „ ... 3	M.D. + ⅓d. per unit 2⅛ and 1⅛, less discount 5 per cent.	2·00 (*c*)	13·0	Total load factor 26·1 per cent.
Newport... ...	4 and 3	2 and 1	1·35 (*b*)	20·9	5 per cent. discount.
Nottingham ...	M.D. 5 (1st 400 hrs. per annum)–1½	1¼	1·25 (*c*)	20·56	
Oldham	M.D. 4 (2 hrs.)–1½ *	M.D. 2 (2 hrs.)–1½ or 500 at 2 per quarter 2nd „ 1¾ „ over 1½ „	1·50 (*b*)	21·06	* Or 1st 1,000 units, 4 per quarter. 2nd „ „ 3½ „ 5th „ „ 2 „ Over 5,000 units, 1½.

Perth	3¾ to 2½	2 to 1½	1·33 (b)	14·96	
Pontypridd ...	M.D. 7–1, 3¾	M.D. 7–1, 3¾	1·50 (b)	15·9	
Rochdale ...	6 100 hrs. per quarter)–2, or 4½ *	2 to 1	1·14 (b)	19·33	* Discount.
Rotherham ...	4	1½, 1 large consumers	1·50	22·51	
Salford	3½, or 1s. per quarter per 8-c.p. lamp equivalent and 1½ per unit	1,000 per quarter, 1½; above; 1, or £1 per H.P. per quarter and ⅓d. per unit	1·26 (c)	23·8	
Southampton ...	4½	3	1·87 (c)	17·2	
Southend ...	M.D. 6 (1st hr.)–3, 4½*	2 or 1, 6 a.m. to 7 p.m., 6 at other hours	1·87 (b)	13·61	* Or £6 10s. per kw. and 1½ per unit.
Southport ...	M.D. 6 (1st hr.), 4 (2nd hr.)–2, or 4½ flat rate	2 and 1½	1·50 (c)	14·32	
South Shields ...	M.D. 7 (1 hr.)–1½, 4	Heat 2 Power 1⅛–1 discount	1·38 (b)	21·59	
Stalybridge ...	4 and 2	2½ to 1	1·00 (b)	36·8	
Stockport ...	3½ less 5 per cent.	1¼ less 5 per cent.	0·78 (a)	26·54	
Sunderland ...	M.D. 4½ (1½ hrs.)–2½, or 4½ with discount to 2½	2½ discount to ⅞	1·69 (b)	19·8	
Swindon... ...	4	2	1·6	14·5	
Wallasey ...	4, reduction of 1 after 2 units per quarter per 8-c.p. lamp	2	1·63 (b)	20·52	
Walsall	M.D. 6 (230 hrs. in half year) –2, or flat 4*	100 units per quarter, 2; 200 " " 1¾; 500 " " 1½; over 1¼	1·50 (b)	16·94	* 10,000 units per annum 10 per cent. discount. 15,000 units per annum 12½ per cent. discount.

(a) Power supply, exclusive of capital charges.
(b) Power supply and capital charges on generating plant.
(c) Power supply and capital charges on generating plant and tramway feeders.
(d) Power supply and capital charges on generating plant and maintenance of overhead equipment.

TABLE I. (*continued*).

Traction and Lighting Stations Combined. Local Authority.

(1908–1909.)

Locality.	Price : Pence per Unit.			Load Factor.	Remarks.
	Lighting.	Power.	Traction.		
Warrington ...	M.D. 6 (1 hr.)–3, or 4	1,000 per quarter, 2 ; over, 1	1·50 (*b*)	22·97	
West Ham ...	3	1	0·99 (*b*)	29·8	
Wigan	5, 4, 3	$\frac{3}{4}$ to $\frac{1}{2}$	1·41 (*c*)	20·08	
Wolverhampton.	M.D. 5 (1 hr.)–2, or 4 to $2\frac{1}{2}$ flat	M.D. 2 (2 hrs.)–$\frac{3}{4}$ *	1·12 (*b*)	21·0	* Or 1d. for not less than 48 hours' use per week.
Yarmouth ...	5	$2\frac{1}{2}$, 2 less 5 per cent.	1·75 (*c*)	15·48	

(*b*) Power supply and capital charges on generating plant.
(*c*) Power supply and capital charges on generating plant and tramway feeders,

article depends on the ratio $\frac{\text{standard charges}}{\text{number made}}$, and in the generation of electricity we have what might be called primary and secondary costs.

The *primary costs* depend only upon the maximum amount of energy that may be demanded at any time and which may be called "fixed costs."

The *secondary costs* are dependent on the number of units generated, and may be called "running costs."

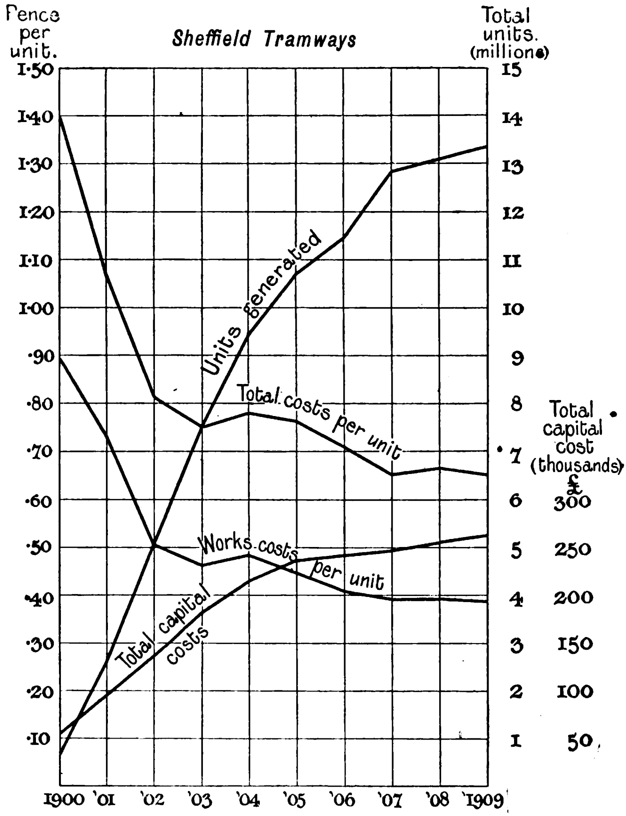


FIG. 1.

The former include interest and sinking fund, etc., on the total cost of generating station and plant which has to be installed for supplying the maximum demand, and may be said to remain fixed for any size of station, but these costs per unit generated diminish in proportion to the output of such station as shown in Fig 1.

The latter are not entirely a constant value per unit generated, but depend on the fluctuating price of coal, etc., and also on the station load factor.

In "fixed charges" may be included :—

1. Interest and sinking fund on land and buildings for generating station, and all plant required for generating and distributing electrical energy, say, to feeder pillars or to the trolley wires.
2. Rent, rates, taxes, and insurance.
3. The provision of a sum each year for depreciation or renewals on above.

In "running costs" may be included all items set out and happily agreed upon and now known as the "Standard Form of Tramway Accounts," viz. :—

Salaries and wages of officials and staff.
Fuel, water, oil, and waste.
Repairs to steam and electrical plant.
Repairs to ducts, feeder cables, etc.
Repairs to power and sub-station buildings, etc.

We now come to the suggested allocation of "fixed" and "running" costs, and to the consideration of points which should determine a fair basis of charging.

In order to allocate on an equitable basis to the lighting and tramway departments their respective proportion of above costs two all-important computations must be made :—

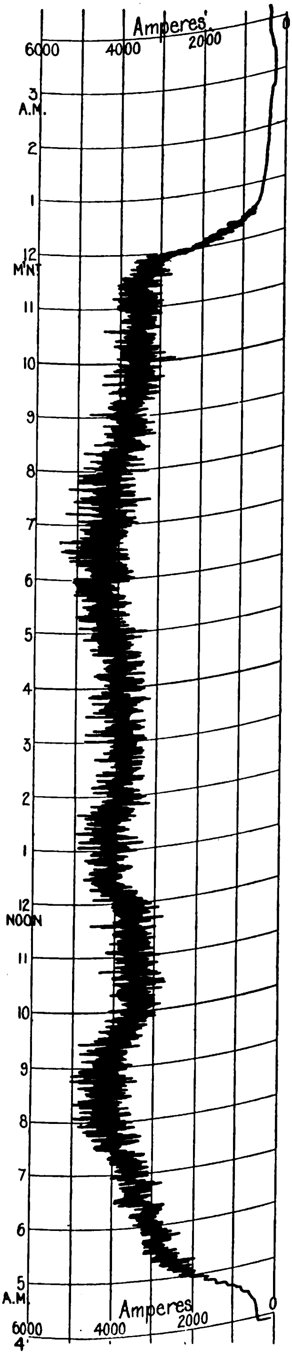
1. The maximum demand in kilowatts per annum required by tramway departments.

This maximum-demand principle is admittedly the fairest system of charging, and the majority of municipal supply tariffs are based on this system, whereby all consumers are supplied on the same terms, and the total costs are divided in the fairest possible manner.

2. The approximate kilowatt-hour consumption per annum.

From the above can be estimated the size of plant required (with reasonable spares), the standing charges of which will determine the principal item under "fixed costs" and the actual "running costs" can readily be arrived at when kilowatt-hour requirements are known.

It must be admitted that there is a greater difficulty in arriving at an equitable "fixed charge" than determining the selling price per kilowatt hour based on a lump sum per annum independent of the number of units sold, plus running costs, with a reasonable percentage of profit to be agreed on. It may be said that the generation of electricity is the same, no matter what use is made of it, and each class of consumer should contribute to the profits of the undertaking (assuming there are any), and all should be supplied under the same maximum-demand terms, notwithstanding the different charac-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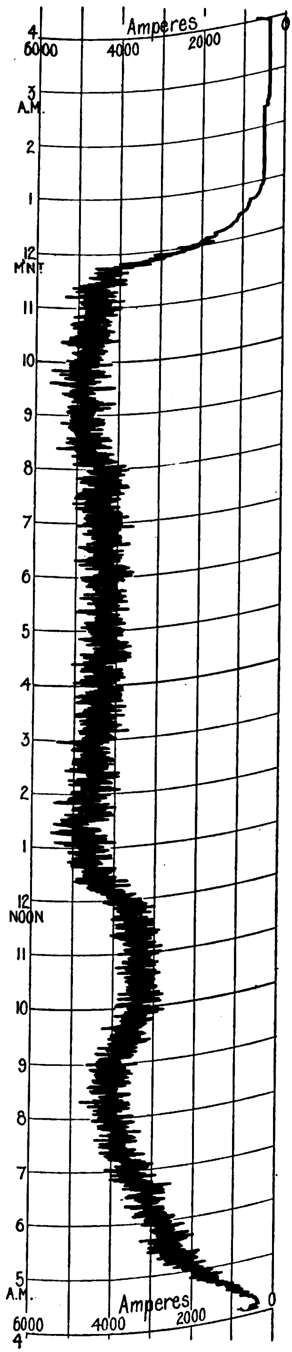
A.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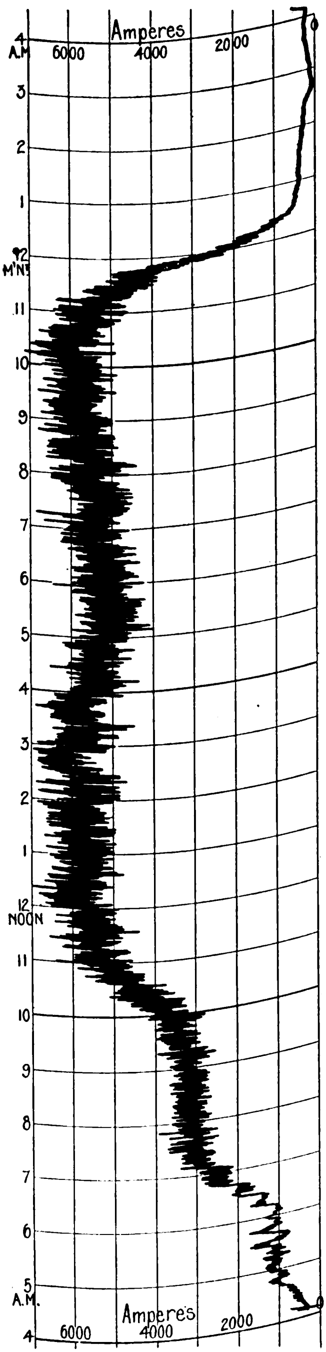
teristics of individual requirements, but it must be remembered that whereas a lighting load lasts on an average, say, 3 hours per day, a tramway load demands a supply of energy for about 16 to 20 hours per day. In the operation of the maximum-demand system it has been found that all domestic lighting consumers have somewhat similar load factors, although the annual consumption may vary considerably. It may be further said that consumers should be charged a minimum rate per unit with sliding scale. It would therefore be obviously unfair to charge a tramways department the same rate per unit as a large power consumer with the same maximum load, as in the former case we have a long-hour demand and often in the latter case only about an eight-hour day demand.

It should be noted that although about 165 million units are sold annually by the supply authorities to tramway undertakings, at a higher rate than under their ordinary power supply tariff, the profit accruing from such business does not show very conspicuously in their respective annual statements of accounts, and the question may well be asked, Why is this? Are there some consumers who will only pay exactly the total cost price of generating electricity at the works? And are there also other large power consumers who can only be obtained by offering them a supply at less than the total cost price—*i.e.*, at approximately the price actually expended at the works per unit generated, ignoring all capital or standing charges? In the author's opinion there is no doubt that agreements are drawn up and millions of units are actually sold under total cost price, but the engineers' claim is, that such business improves their station load factor. It would be equally logical for such engineers to admit that a certain proportion of the total number of consumers were being charged considerably above total cost price, and that instead of each consumer bearing a fair and reasonable proportion of the costs incidental to the whole of the capital charges (if such be the policy), such charges are inflicted only on certain consumers, notably on tramway authorities. In other words, tramway departments have to bear costs which legitimately belong to the lighting and power department.

It is manifestly equitable that the plant required to meet the maximum tramway demand at times of "peak load"—including spares—should be the measure taken for allocating the capital charges to a tramways department, but peak load in a tramway station may almost be said to be non-existent as compared to a lighting station. This is shown on Load Charts, A being an ordinary day load with 188 cars; B a Saturday load with 206 cars; and C a Bank Holiday load with 256 cars.

The enormous fluctuations in load and strains and stresses which our American friends predicted at the inception of electric traction in England are in practice unfounded, and consequently the costs in, say, keeping boilers under steam and for a "stand-by staff" for this theoretical "peak load" are infinitesimal; yet engineers of combined stations do not appear to look upon these costs as "running costs," but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C.

invariably include them under "fixed costs." Now, the fair proportion of these so-called "fixed costs" to actual "running costs" is a debatable point.

Comparative Costs.

For general comparison between costs so determined by supply authorities and separate self-contained systems, actual figures are preferable to hypothetical estimates, and the two cities of Bradford and Sheffield may be taken as a fair comparison to show the basis of charge in the former case and the actual costs in the latter.

For the year ending March 31, 1909, the Tramways Department of Bradford purchased 10,131,499 units at a cost of £47,384 11s. 8d., the price per unit being 1⅛d. from the Corporation works, and 1¾d. per unit from the Shipley Urban District Council. For year ending March 25, 1909, the Sheffield Tramways Department generated 13,373,958 units at a cost of £21,758 12s. 8d., excluding capital charges, and including all charges at a total cost of £36,765 14s. 9d., the works costs being at the rate of 0·390d. per unit, and total costs per unit = 0·659d., including maintenance of ducts and cables up to feeder pillars.

Under "fixed charges" we have for a low-tension tramway station of 4,450-k.w. capacity :—

	Pence per Unit Generated.
1. Interest at 3·13 per cent. and sinking fund at 2·05 per cent.	0·241
2. Rent, rates, taxes, and insurance	0·028
3. Depreciation and renewals based on 1.89 per cent. per annum on total capital expenditure. Proportion on power station, buildings, plant, cables, etc....	0·102
Total	0·371

It appears that about double the above total is generally considered directly chargeable to tramway departments by electric supply departments in determining selling price per unit.

For instance, the Manchester Electric Supply Department in selling approximately 29½ million units to the Tramways Department for year ended March 31, 1908, in addition to above usual items, also add items included in "running costs"—viz., coal, oil, waste, water, salaries and wages, repairs and maintenance of plant in the following proportions, viz. :—

Coal, 27·35 per cent. of amount included in "running costs" is also included in "fixed charges."
Oil, waste, water, etc., 27·35 per cent., ditto.
Salaries and wages, generating station, 100 per cent., ditto.
Repairs and maintenance of plant, etc., 33·33 per cent., ditto.

TABLE II.

Traction Stations separate. Local Authority (generating over 2,000,000 Units per Annum)

Locality.	Price: Pence per Unit.		Traction per Unit Generated.		Load Factor.		Remarks.
	Lighting.	Power.	Works Costs.	Total Costs.	Lighting and Power.	Traction.	
					Per Cent.	Per Cent.	
Birkenhead	Summer. M.D. 6 (½ hr.), 3 (½ hr.)–1½ Winter. 6 (1½ hr.), 3 (1½ hr.)–1½, or 4 flat	1,500 units, quarter 2; to 3,500 " " 1½; over, 5,000 " " 1	0·64	—	15·5	25·44	
Cardiff	M.D. 7–2, or 3½	1½ (large Consumers' special tariff)	0·37	0·75	17·87	37·1	Sells in bulk to Lighting Department at 0·8
Glasgow	M.D. 3½–¾ (1st, 730 hrs. per annum), or 3	M.D. 1½ (1st 1,000 hrs. per annum) ¾ after; or no current between 3.30 p.m. and 6.30 p.m. Nov., Dec., Jan., 1	0·350	0·757	16·83	39·8	
Huddersfield ...	4, less discount	M.D. 2 (2 hrs.)–1, discount	0·42	0·66	11·61	40·0	
Hull	4½, 1st 6 months; 4, 2nd "	M.D. 5 (1 hr.)–2, or 1½ (1st 6 m's.) or 2 to 1 (2nd 6 m's.)	0·65	0·825	12·62 (*)	46·3	

* This column does not include depreciation allowance.

TABLE II. (*continued*)

Traction Stations separate. Local Authority (generating over 2,000,000 Units per Annum).

Locality.	Price: Pence per Unit.				Load Factor.		Remarks.
	Lighting.	Power.	Traction per Unit Generated.		Lighting and Power.	Traction.	
			Works Costs.	Total Costs.			
					Per Cent.	Per Cent.	
Leeds	4, and 1	2 to $1\frac{1}{8}$, 5% discount	0·3597	0·7600	17·07	38·44*	* D.C. plant only.
Leicester	4	2	0·39	0·6213*	10·8	27·0	* Not including repairs to ducts and feeder cables
Newcastle-on-Tyne	Company (Average price	supply obtained, 1·12.	0·363	0·825	19·78	36·0*	* If on plant capacity, 22·1
Portsmouth	4, special rates to large consumers	$1\frac{1}{2}$	0·543	0·924	14·43	24·0	
Sheffield	4	2 to 0·6 for special consumers	0·39	0·659 (This column does not include depreciation allowance.)	15·63	38·1*	* On plant capacity, 34·3

On a basis of 29½ million units per annum the "fixed charges" per unit sold are as follows:—

Coal	0·043
Oil, waste, water, etc.	0·004
Salaries and wages	0·069
Repairs	0·064
Rent, rates, taxes	0·087
Management, etc....	0·036
Interest and sinking fund	0·441
Renewals suspense account	0·121
Total	0·865

As this total of "fixed charges" alone amounts to more than the total generating costs in a separate generating station, it will be interesting to dissect the items in order to compare them with the average costs in a low-tension tramway power station.

1. *Coal.*—It is assumed by engineers of combined stations that a very considerable quantity of coal is burnt in keeping boilers under banked fires for "peak loads," and the expenditure under this head at Manchester amounts to 0·043d. per unit as a fixed charge. The author ventures to criticise the justice of this charge and to point out that about two million units could be generated in a tramway station with this estimated quantity of coal—assuming price to be approximately 10s. per ton—and it is usual for all coal consumed to be included in "running charges."

2. *Water, Oil, and Waste, etc.*—This item also appears to be high, and amounts to about 0·004d. per unit as a fixed charge. In a tramway station generating about 14 million units per annum, this cost should be sufficient for all oil, waste, and other stores, even where reciprocating engines are in service, and in respect to water, the "fixed charge," if any, should be a very small one.

3. *Salaries and Wages.*—This item in the "fixed charges" under review amounts to 0·069d. per unit, and appears to be exceptionally high in view of the fact that under "management expenses" a further fixed charge of 0·036d. is allocated, making a total of 0·105d., which is considerably higher than the *total* charge under "management, salaries, and wages" in a low-tension tramway station.

Presumably in combined stations under "management charges" are included administrative salaries and wages of clerks, meter inspectors, and others whose salaries and wages are not allocated to any special department. Here, again, the great difference between a tramway department and the general consumer is apparent. Meter readings are simple, and accounts for tramway departments are usually paid quarterly on one bill, but the author feels inclined to think from the above figures that tramway departments are being charged *pro rata* for management, etc., with ordinary customers, notwithstanding

the fact that the latter require an elaborate book-keeping system, also meter inspectors, and large clerical staff.

Repairs and Maintenance.

The repairs to buildings, plant, mains, meters, etc., are estimated to be equal to 0·064d., which is about the same average per unit required to cover all repairs and maintenance to all steam and electrical plant, also power and sub-station buildings in a tramway power station, and including repairs to ducts, cables, etc., up to the feeder pillars, amounting to 0·016d., the total cost would be about 0·079d., so that a fixed charge of 0·064d. certainly appears to be on the safe side.

Rents, Rates and Taxes, etc.

The percentage of "fixed charges" under the above items debited to traction units is 37·12 per cent. of total, which amounts to 0·087d. per unit. In the separate tramway station under review, the proportion of rates, taxes, and insurance on the entire station amounts to 0·028d. and including rates and taxes on cable ducts, cables, etc., to 0·056d. The apparently high former figure is doubtless accounted for by additional buildings and plant required for converting high-pressure current to the low-pressure tramway feeders, and possibly includes proportion of Income Tax, although in the author's opinion this should appear only in the profit and loss account, and cannot very well be estimated when determining a selling basis or arriving at the cost of current production.

Interest and Sinking Fund.

These capital charges vary slightly each year and are dependent on the length of the period of loan and the rate of interest at which money is borrowed.

An amount equal to 0·441d. per unit sold is computed in the combined station selling 29½ million units per annum and 0·241d. is the actual figure in the tramway power station generating about 13½ million units per annum. The great difference may be due to the provision of land, buildings, and plant, mains and feeders required for transforming high-tension alternating current to low-tension continuous current feeding the trolley wires.

Renewals, Suspense, or Depreciation.

The amount per unit which has been charged under this head in the combined station is 0·121d. or 1·68 per cent. per annum of capital expenditure. To bring into line a self-contained undertaking it may be assumed, as is done in Sheffield, that a sum equal to 0·75d. per car-mile is required to be set aside annually to build up a renewals fund or 1·89 per cent. per annum of total

TABLE III.

Lighting and Traction Stations combined under one Local Authority supplying Energy to Tramways under another Local Authority.

Locality.	Price : Pence per Unit.			Load Factor.	Remarks.
	Lighting.	Power.	Traction.		
Bootle (Liverpool)	M.D. 6–1½, or 3¾	Units, 500 per quarter, 2 over, 1	Units per annum. 375,000 ... 1½ over ... 1	25·09	
Eccles (Salford)	M.D. 7–2, or 4	2½ to 1	Units per annum. 500,000 ... 1⅓ over ... 1	21·79	
Heywood (Bury and Rochdale) ...	6, 1st 12 units per 16-c.p. lamp per annum, 3 after, or 4½	2½ to 1½	1·3	—	
Radcliffe (Bury)	4 to 3, sliding scale	2 to 1 on load factor	1·5	—	
Shipley (Bradford)	4¼	1¼, less 2½ % discount	1·7	—	

capital expenditure. The proportion of capital expenditure on power station and all cables, etc., to that of the entire undertaking is 22·47 per cent. and spread over, say, 10 years, amounts to 0·102d. per unit, which estimate has proved so far to be sufficient for extraordinary renewals and obsolescence, as ordinary repairs and renewals are directly charged to power account.

In computing the selling price to a tramways department it should be remembered that sufficient is estimated in the interest and sinking fund to liquidate entirely the capital expenditure on land, buildings, plant, and cables required for tramway purposes at the expiration of period of loan. Still we find that invariably a very considerable sum is put aside for the building up of a depreciation fund or renewals suspense account, which really means that after 25 or 30 years the electric supply department may have a complete generating station, plant, and cables fully paid for, and possibly in addition a substantial balance at the bank. This point of view—viz., the valuation asset or the then market value of the undertaking is often ignored.

Comparative Differences.

Having now dealt with a comparison between a combined and separate generating station, a few words should be said bearing on certain points which are not comparable in the two instances under review. In the first place, the comparison has been between a high-tension alternating-current station—principally—and a low-tension tramway station, and between units sold and units generated. These facts figure largely in the comparative data, for it is well known that where high-tension current is transformed and distributed, the total cost per kilowatt installed amounts to between £40 and £50, and at Manchester it amounts to about £61; whereas in a low-tension continuous-current supply the initial cost of all generating plant and freehold buildings need not be more than £35 per kilowatt, and including cost of all ducts, cables, etc., £50 to £55 per kilowatt, and in the former case the combined conversion and transmission losses and also running costs are considerably higher than from the latter supply. These are undoubtedly the factors which have a most important bearing on the subject of tramway tariffs, and which, in the author's opinion, often negative the benefit which should be received by a tramways department obtaining electrical energy from a combined general supply and traction works.

Whilst it must be admitted that with a continuous-current supply the area of the feeding zone from the generating station is limited, it should be borne in mind that in the majority of cities and boroughs the length of tramway routes from the centre of city—or power station—to termini is not more than, say, 4 miles, in which case low-tension current can economically be transmitted, and where tramway authorities have a self-contained system there is no occasion

TABLE IV.

Lighting and Traction Stations combined under a Local Authority supplying Energy to Tramways under a Company.

Locality.	Price: Pence per Unit.			Load Factor.	Remarks.
	Lighting.	Power.	Traction.		
Aberdeen (Suburban Tramways Company)	M.D. 5½ (1 hr.)–1½	M.D. 2½ (1 or ½ hr.)–1	2·25*	18·46	1·18 to Corporation Tramways
Carlisle (City of Carlisle Electric Tramways Company)	Units per annum. 1,000 ... 5 3,000 ... 4¾ 6,000 ... 4½ 12,000 ... 4¼ over ... 4	3¼ and 1	1·63	16·61	
Cheltenham (Cheltenham and District Light Railway)	5½ to 2½ (sliding scale on M.D.)	2	1·4*	13·4	*Average: 1·6, 1·1, 0·75.
Dartford (Urban District Council Light Railway, J. G. White and Co.)	M.D. 7–2, or 4	2½ to 1½ (discount, 5 per cent.)	2 to 1½	—	
Dudley and Stourbridge (Dudley, Stourbridge, and District Electric Traction Company)	2-rate meter. 6 (2 hrs.)–1½ (22 hrs.), or 4 flat	6 and 1	Units. 150,000 ... 2 200,000 ... 1·9 250,000 ... 1·8 300,000 ... 1·7 350,000 ... 1·6 400,000 ... 1·5 over ... 1·0	14·65	
Greenock and Port Glasgow (Greenock and Port Glasgow Tramways Company)	4–1½	2½–1	500,000 ... 1·5 next 200,000, 1·25 ,, 200,000, 1·0 over ... 0·85	18·51	
Middleton (Middleton Electric Traction Company)	4–3	2–1½, sliding scale	1½–1, sliding	15·05	
Tynemouth (Tyneside Tramway and Tramroads Company)	M.D. 100 hrs. in summer 150 hrs. in winter 5–2	1st 100 hrs. ... 2½ after ... ... 1¼ or flat ... ... 1½ or off peak load 1⅛	Unit to 200,000, 1¼ over this, 0·625	15·7	

to instal high-tension plant under the above conditions, consequently the capital charges are diminished and total costs present a favourable aspect when compared with cost of supply from a combined station.

It has been suggested by many tramway managers that under the same municipality the tramways department should not be charged a higher price per unit than the estimated total cost of production from a separate station.

This dictum appears reasonable, for there is no doubt that in a properly designed combined station generating costs and total costs should be lower than in a separate station, but from Table I., one finds that they are appreciably higher, and tramway departments fail to receive the expected benefit derived from combination.

Opinions differ as to the fairness of the policy or principle of dissociating the ordinary lighting and power plant with its high "service" charges from the tramway supply in computing a basis of charge, but it is well known that many engineers of supply undertakings in computing selling price per unit to large power consumers only charge such consumers the capital charges on plant and mains installed for such service, with the addition of running costs. This would perhaps be excusable if such a policy so reacted in lowering the cost of production that the lighting consumers had the benefit of a reduced tariff; but we often find that no such reduction takes place, and it remains to be seen whether the policy will eventually prove disastrous where a power supply predominates and the number of lighting consumers or revenue obtained from them diminish. The author ventures to express the opinion that the above preferential treatment is justifiable where tramway departments are with a reasonable profit supplied from a combined station, for not only is the load factor known, but the all-important diversity factor can also be calculated and a bulk supply to tramways effects a general reduction in generating costs.

Main Cables and Feeders.

As a tramways department should be in a better position to estimate sectional area of positive and return cables, and to set out suitable methods of distribution and calculate average and prospective load factors on such cables, it is desirable that the cables should be laid and maintained by the tramways department, especially as Board of Trade tests have to be taken and submitted periodically.

Another point which is an important one is that of transmission losses and drop in pressure, for unless a fairly constant voltage is maintained, current consumption and speed of cars suffer in consequence: hence it is suggested by the author that it is in all respects more satisfactory for supply authorities to supply electrical energy in bulk whether from one power station or from sub-stations, and for the tramway departments to arrange and maintain their

own cables. We have now many instances where all cables are laid and maintained by electric supply departments up to feeder pillars, and also many tramway undertakings where all cables and feeders are a part of their system, but this does not appear, according to published accounts, to make any material difference in cost of electric supply from a combined station.

Meters.

Very caustic remarks have been made relative to the accuracy of meters used for registering units to tramway departments, but it can truly be said that if watt-hour meters are used and are maintained in an efficient state, their accuracy is well within the limits allowed by the Board of Trade, and in the author's experience, with a standard high-capacity meter taking the entire output of a station compared with the readings from twenty separate meters on different feeders, the inaccuracy has never been greater than 0·8 per cent. over a period of three years.

As tramway departments appreciate that power lost on mains and distributing feeders costs as much as power actually taken by motors on cars, they themselves should be responsible for the length and sectional area of all cables, so that where electricity is metered from one generating station or from sub-stations no disputes can arise as to transmission losses due to cables being laid on a too economical basis.

It is furthermore suggested that accurately calibrated watt-hour meters should be owned by tramway departments, so that the same could be put into service at any time as a check on the instruments used by the supply department.

Stand-by Plant.

It is generally admitted that the conditions and requirements in a supply station for lighting and power purposes compared with a tramway power station are quite different owing to diversity of load, and the increased running hours of the latter would appear to necessitate a larger proportion of stand-by plant, but on a tramway system with a given number of cars and, say, a standard time service, actual power requirements are always known, and there is not that diversity factor which is manifest in a general supply department feeding various industries and which varies from about 1·25 to 1·65, whereas in a tramway supply the diversity factor is approximately 2·95 under ordinary daily running conditions, and on exceptional days, such as Bank Holidays, is reduced to about 2·75. In order to provide a safe margin of spare plant to guard against breakdown and to provide for periodical overhaul, 25 per cent. above the maximum observed load should be sufficient, but this percentage, of course, depends largely on the class of plant installed and its overload capacity, together with local conditions.

It should also be borne in mind that the heaviest tramway loads

occur on such days—notably Bank Holidays—when the lighting load is considerably below normal; in fact, it may almost be said that at all times when a tramway demand is at a maximum the lighting and power demand is at a minimum with the exception of ordinary evening peaks and Christmas Eve. Therefore, if suitable plant is installed for general power supply purposes ample should be available for these exceptional peak loads with 25 per cent. spare plant.

SUMMARY.

Having dealt with the principal points affecting the determination of costs or selling price of electricity to tramway departments, the suggestions for discussion may be summarised as follows:—

1. *Fixed or Capital Charges.*—To be based upon and calculated only on that portion of the undertaking which is essential for the actual generation and distribution of power to tramway departments.

2. *Management Charges.*—To be made up of salaries, insurance, rates and taxes, and in certain cases proportion of Income Tax as determined by the respective departments, all to be based on the kilowatt capacity of plant employed only for tramway supply.

3. *Running Charges.*—To be "works costs" made up of coal, water, oil, and waste; salaries and wages of staff engaged in generation and distribution; also repairs and renewals of buildings, plant, ducts, and cables. As the cost of coal averages from 50 to 55 per cent. of the total works costs, in basing a price per unit to tramways departments a clause should be inserted in all agreements extending over one year, whereby every shilling increase or decrease in cost per ton would mean a fraction of a penny per unit (dependent on price of coal) to be debited or credited to tramway departments.

It is not suggested that the "running costs" should be taken only on the plant employed for traction purposes, but on the entire station, as a tramway load reduces the cost of production, and the scale of charges should follow approximately the curve or line shown on Fig. 1.

4. *Depreciation, Renewals, and Obsolescence.*—The percentage suggested could be based either on units generated or sold or be calculated on capital expenditure on buildings, plant, and mains required for tramway supply. Committees of various municipalities have directly opposite views as to an adequate depreciation fund, and the allowance made by the Income Tax Commissioners in calculating Income Tax upon municipal undertakings is often ignored. The financial policy adopted in Glasgow, for instance, cannot be followed by many towns. Still, it is regrettable to see the policy of some municipalities where the entire profits are put to relief of rates; but, needless to say, such action is disapproved by the officials concerned.

From the author's fourteen years' experience in electric tramway work a percentage of 1·75 per annum on the entire capital expenditure on buildings, plant, and cables should be considered a fair and reasonable allowance for depreciation and obsolescence. No hard and fast

rule can be laid down, as so much depends on local circumstances and period of loan, for where the period is a short one it does not always seem desirable to supplement the sinking fund by a depreciation fund, assuming that the annual sum so set aside is sufficient to cover depreciation.

5. *Profit from Tramway Departments.*—It is unreasonable to expect a combined station to supply current to a tramways department without profit, and it is suggested that from 3 to 5 per cent. profit should be charged only on the "running costs."

In conclusion, it should be mentioned that this paper is not dealing with the question of separate *versus* combined generating stations, neither is it an attempt to criticise or deprecate combined stations or to suggest what is best for a particular town or municipality as a whole, the object being to open up certain debateable points which materially affect the price per unit charged to tramway departments compared with actual costs in self-contained undertakings, the latter being invariably lower than the former.

TRAMWAY POWER CHARGES.

TABLES.

I. Lighting and Traction Stations combined under a Local Authority.

II. Traction Stations separate—Local Authority—(generating over 2,000,000 Units per Annum).

III. Lighting and Traction Stations combined, under one Local Authority, supplying Tramways under another Local Authority.

IV. Lighting and Traction stations combined under a Local Authority supplying Tramways under a Company.

V. Maximum, Minimum, and Mean Prices in Tables I. and II., and also for 17 Systems in Table I. using over 2,000,000 Units per Annum.

Number of cases taken :—

Table	I.	65
„	II.	10
„	III.	5
„	IV.	8
	Total	88

These Tables are largely compiled from *the Manual of Electrical Undertakings* and *the Electrical Times* (1909).

TABLE V.

Maximum, Minimum, and Mean Prices in Tables I. and II., and also for 17 Systems in Table I., using over 2,000,000 Units per Annum.

Reference to Table.	Pence per Unit.			Remarks.
	Maximum.	Minimum.	Mean.	
No. I. (*b*)	1·87	0·93	1·3776	
(*c*)	2·00	1·04		
(*d*)	2·13	1·50		(*d*) Only three cases including capital charges, and maintenance of overhead equipment.
No. II.	0·924	0·659	0·75653	
17 of No. I.	1·78	0·99	1·225	

The 17 systems referred to are: Birmingham, Blackburn, Bolton, Bradford, Burnley, Croydon, Dundee, Halifax, Liverpool, Manchester, Nottingham, Oldham, Rochdale, Salford, Stalybridge, West Ham, Wigan.

DISCUSSION.

Mr. Snell.

Mr. J. F. C. SNELL: I am sure that all who have been connected with municipal supply will be glad if some fair and reasonable basis can be arrived at for assessing prices between tramway and electrical departments. I must, however, object to Mr. Yerbury's general statement on page 586, that "tramways departments have to bear costs which legitimately belong to the lighting and power departments." That may be true in certain cases, but I do not think it is true as a general rule. It is very difficult to compare costs in different towns without reducing them to a common datum. I think the tables of costs in the technical papers are largely responsible for the friction which undoubtedly exists between the tramway and electrical departments in various towns, because, as we all know, the *works costs* only are given for independent tramway stations, whereas in the units purchased from combined stations charges other than the pure works costs are included. In other words, the combined department has very properly to cover its capital charges, rent, rates, taxes, a portion of management, and so on. Another mistake frequently made is to attempt to compare tramway supplies from various kinds of stations. I think it would be fairer to divide them into four classes, viz., alternating stations with rotaries for supplies above 5 million units as the first class, the same kind of station supplying less than 5 million units as the second class, direct current above 5 million units as the third class, and direct current below 5 million units as the fourth class. It

is only an empirical division, but still it would be fairer in comparing town with town to class them in that way than to consider them all alike, as is too frequently done to-day. Then in dealing with stations built under the Tramway Acts, the period for the redemption of the loans is usually 30 years, whereas in the case of combined stations the period for redemption was originally 25 years, and the Local Government Board reduced it to an average of 22 years; but now one more frequently finds it even at the low figure of 17 years. If one takes the average period for the redemption of loans from the combined stations as 20 years, and the 30-year period stands for independent tramway stations, the difference between the annual repayments in the two cases is very considerable, nearly 2½ per cent. on the capital expenditure, which means a considerable addition to the cost per unit. It is quite true that some of the tramway authorities very properly add to their sinking fund repayments a sum sufficient to bring down the average period for the renewal of the plant to the lower figure of 20 years, but that is not always done. Then one has also to consider that the plant used for tramway purposes in a combined station has, while it is supplying tramways, to be isolated for tramway supply, and consequently less benefit is obtained from it than when supplying power and lighting from that plant in the combined station. Another point is that in the record of prices in the technical press the units are those generated at the tramway power house. There, again, one has to subtract the units which are used for internal lighting, and in the case of condensing stations the units used for the auxiliary motors, and to add the rent, rates, and taxes, and a proportion of the management expenses, and I submit, with all respect to my tramway friends, that one ought to add, on a commercial basis, a reasonable sum for profit to cover all the contingent risks which undoubtedly exist in the supply to a tramway. Another very important matter to be taken into consideration is the variable load factor. I have been astonished, in some of my own investigations, to find what a variable factor that is. In the case of Sheffield I think Mr. Yerbury will agree that the annual load factor is about 40 per cent.; in other cases it is more than 50 per cent. On the other hand, many tramway concerns give an annual load factor of only 22 per cent., and 25 to 30 per cent. is a fairly general figure. All those figures have to be taken into consideration when attempting to compare the costs of supply to various tramway concerns. I am sure that is a most fruitful cause of irritation in many towns between the tramway department, on the one hand, and the electrical department on the other. I think the author has adopted an incorrect method in attempting to compare a simple direct-current station like Sheffield with a 3-phase station like Manchester. The two things are not strictly comparable at all. If Mr. Yerbury had taken Glasgow, which is an independent 3-phase station, and compared that with Manchester, then he would have been comparing like with like, although the output of Glasgow is, I believe very nearly twice the output of Manchester *quâ* tramways. And what

Mr. Snell.

Mr. Snell. do we find in Glasgow? Although in the *Electrical Times* the actual costs are given as 0·35d. per unit, if one takes the Glasgow statutory accounts and allocates the amounts for buildings, sub-stations, sub-station plant, and other plant, the price is raised to 1·2d. instead of 0·35d. per unit, and that compares, I am told, with a figure of 1·04d. in Manchester, or a flat rate of 1d. in the near future. So when one compares like with like, the two prices are not dissimilar; and in the case of Manchester, which I have taken quite haphazard, the combined station has the advantage. If one takes smaller stations, so as to break them into the classes which I have spoken of, I admit that the independent stations have the advantage. I have taken again, quite haphazard, four stations, Birkenhead, Northampton, Portsmouth, and Reading, each of which may be taken to be quite typical stations in various parts of the country. Their average output is 1¾ million units per annum; the average price as published is 0·62d., but the average price including the actual charges, based upon the authority of the report of an eminent tramway manager, is 1·16d. at least. Mr. Yerbury tells us that the average of the several stations up and down the country is 1·377d., but that includes a very large number of stations whose output is under half a million, so that there is not that wide discrepancy which the author suggests in his paper. There is one other aspect of the question, although, possibly, an aspect with which we as engineers are not very much concerned; still it is a factor with which municipal engineers have to deal. I refer to the question of combining municipal stations. I think it is admitted, except in very large cases—and even in those it is a good principle—that it is advisable to combine the stations, and that if this is not done, for instance, for a small tramway system in a town having its own electric supply, both a tramway station and a supply station will be necessary, with small units, and therefore at a greater cost per kilowatt. There will also be high annual charges for wages and salaries, which means that, put it how one will, the total cost to the municipality as a whole is greater in the case of the two separate stations than in the case of the combined station. There is this great advantage in a combined station—a point which our tramway friends very often forget—that while in some cases they are paying more than they would if they had their own independent station, I think the average charges paid by the tramways to the supply departments are equitable. In some cases, no doubt the price which is paid by the tramway department is too low. But as the electrical department develops and grows, I suggest that the tramway department, which will not grow with equal steps, will be in a better position to get a reduction *in futuro* than if it had an independent station without the same chance of growth. Now, as regards a standard price, I think, if I may say so, that there is a proper way of settling the price once and for all between the various departments. I have found it answer well in at least three cases. I take the ascertained maximum demand of the tramway department—

it does not matter at what time of the day it happens—and I also take the coincident maximum demand, which is usually a different figure from the real maximum demand—that is to say, the demand of the tramways at the time of the maximum peak upon the combined station. To be quite fair, I take a mean of those two figures, and I will tell you why. The coincident demand represents the demand of the tramways as a whole upon the steam-raising plant; the real maximum demand means the demand upon the steam using and electrical plant. Therefore I suggest it is fair to everybody to take the mean of those two figures. Then, without allocating—as Hopkinson has suggested—any proportion of the coal to the standing charges, I merely take as the standing charges the real sinking fund and interest paid on the power house equipment, and on the sub-stations, if there be any; the management (less the charges of the distribution department, which have nothing to do with the tramways, as a rule); the rent, rates, taxes, and insurance, and the wages of the power station, or if it be a 3-phase station with sub-stations, of the latter as well. I suggest that those represent the real fixed charges, which, divided by the total kilowatt demand upon the combined station, gives the resultant charge per kilowatt. Multiply that figure by the ascertained demand upon the tramway and the result will be the proportion of fixed charges which the tramways ought to pay towards their own supply. Finally, taking running costs, that is the remaining cost of coal, oil, and repair charges to the plant (not to the mains), I divide that by the total useful units delivered to the switchboard, that is, the units generated less the units used within the station. That gives a running charge per unit delivered to the switchboard. If, as I suggest they should be, the tramway units are measured at the power station switchboard, the actual units supplied to the tramways at that point multiplied by the running charge will represent their proportion of the running costs. The addition of the fixed and running cost gives the net costs of production without any allowance for profit. Seeing that the combined station has to bear all the risks of variation in the price of coal, or of damage by fire, explosion, or other causes, one adds according to the particular town a certain percentage. In some cases it is 5 per cent., in others it is 7½ per cent., and that represents the real price which the tramway department ought to pay to the supply department. I suggest that if that method be adopted it will really give the true charge for the tramway supply, and the figures can be re-assessed triennially. Mr Snell.

Mr. STUART RUSSELL: I think the author has rather confused the question by his division into fixed and running costs. I have always been accustomed to believe that the fixed charges are entirely independent of the number of units generated, and that the total running costs are proportional to the units generated. The author objects to that division, and to the inclusion in the running costs of any portion of salaries, wages, fuel, water, oil, waste, and repairs. But in another part of the paper he rightly points out that what he designates the running costs will vary according to the load factor. The reason for Mr. Russell.

Mr. Russell.

including a portion of those charges amongst the fixed charges is to take into account that reduction in the cost of generation which does follow an increased load factor. I am inclined to think that the paper would have been a good deal clearer had that division been adopted; that is to say, if there had been included amongst the fixed charges all capital charges, interest, sinking fund, depreciation if any, management, rent, rates, taxes, insurance, salaries and wages of officials and staff at the station, and a percentage of the fuel, water, oil, and repairs. This is apparently what, according to the figures quoted, has been done in the case of Manchester. In examining those figures I cannot help thinking that there has been some mistake. In the tables at the end of the paper the total charge to the Tramway Department is given as 1·04d., including capital charges on generating plant and tramway feeders. The fixed charges total up on page 591 to 0·865d., and at the bottom of page 588 it is stated that in the fixed charges are included 27·35 per cent. of the cost of the coal included in the running costs; and 27·35 per cent. of the cost of oil, waste, and water included in the running charges are also included in the fixed charges. Therefore the total cost of the coal, oil, waste, and water, must be very nearly five times that which is included in the fixed charges, and will amount to 0·22d., giving 0·172d. to add for running costs. With regard to repairs, one-third of what is included in the running costs is included in the fixed charges, consequently the running costs must be three times the amount given amongst the fixed charges, or 0·192d. Adding those two items to the total of 0·865d. we get a total cost of 1·23d. It would appear, therefore, that there is some slip in the making out of this table, as the actual charge for supply according to the table given at the end of the paper is 1·04d. or very nearly ¼d. less. With regard to the division of the charges as between a tramway supply and a lighting and power supply, there are in most cases certain portions of the plant provided solely for the use of one supply or the other, such as tramway feeders, or distributing network services for lighting and power. In allocating the costs, one would naturally take the charges for capital expended on those special items and charge them to the supply which is making use of them. The charges on the remainder of the capital expenditure, which is common to both supplies, I would divide in proportion to the relative maximum demands. The suggestion by Mr. Snell that, instead of the actual maximum demand of the tramway, a mean between its maximum demand and the demand at the time of the maximum lighting demand should be taken, seems to be of importance, and to give a fairer division than taking simply the maximum demand of the station. With regard to management, insurance, rent, rates, and taxes, they should be divided in the same manner and in the same proportion as the capital charges. The salaries and wages of the station are a rather more debateable question, but I have found that very correct results are obtained by including the whole of them amongst the fixed charges. I am speaking now, of course, of the division of the cost between

two different kinds of supply given by the same station. With regard to coal, stores, and repairs, I believe, in this case also, a certain portion should be included in the fixed charges. When I was in charge of the Brussels Central Station many years ago I made a number of tests on the stand-by losses, which led me to the conclusion that in a lighting station—and there were only lighting stations then—with a load factor of 17 or 18 per cent., about 25 per cent. of the total cost of coal and stores should come in as fixed charges. I have since heard from Mr. Pearce that he also has made tests which have confirmed this figure. He actually adopts, I believe, the same percentage for a lighting station having a load factor of a little less than 20. From this, for the purpose of estimating, I have worked out a convenient expression giving the amount of the fixed charges for different load factors. If A be the total expenditure on coal, stores, and repairs, and L the load factor, I find that the amount of the fixed charge should be $\frac{6\ A}{L + 6}$, and therefore, with a tramway load factor between 40 and 50, instead of 25 per cent. of those charges being fixed charges, the percentage comes down to the neighbourhood of 10. Of course, there are special conditions which will have to be taken into account in every town, which no one without the complete figures of that town before them can allow for; but, for the general division of the costs, the method and the figures I have given will, I believe, give very accurate results. Mr. Russell

Mr. E. W. Cowan: On page 576, the author has laid down certain fundamental principles, from which he draws his conclusions in the remainder of the paper. The first of those principles is that the charge as between one consumer and another should be equitable. Of course, no one will dispute that; but we may not be in complete agreement as to what actually constitutes equitable treatment. The author says, "Considering the low price now being charged by electric supply departments for heating and general power purposes, it seems at first sight strange that a much higher price is invariably charged to tramway departments, notwithstanding the load factor," and so on. May it not be that a contributory cause of the higher price, if it is true that it is a higher price, may be due to the fact that power for locomotion purpose is really worth more than power for stationary use, or may have a higher market value? I take it that the author would not consider that side of the question, because it is not usual amongst electrical engineers to take account of the demand side of those forces that influence price. At the bottom of page 576 the author also says, "It is universally admitted that the price at which any commodity can be sold is determined, firstly, by its entire cost of production; and, secondly, by the number or quantity sold." I think that is scientifically inaccurate. The price of a commodity is not determined by its cost of production nor by the quantity sold. The quantity made or sold is a function of the cost; but the price of any commodity is surely determined by the law of supply and Mr. Cowan.

Mr. Cowan. demand. It is influenced by cost, and it is influenced, of course, by the number or quantity sold; but it is determined by the law of supply and demand. Just incidentally I may mention, in regard to the influence of the number or quantity sold, that it depends upon the nature of the commodity. Sometimes a larger number means a higher price per unit, as in the case of agricultural produce; sometimes, as in the case of labour, it has no effect at all; and in the case of electricity it reduces the price. Then, again, at the bottom of page 576 the author says, "The price of manufacturing any article depends on the ratio $\frac{\text{standard charges}}{\text{number made}}$"; but he omits any reference to the element of demand. I submit it is impossible to ignore that element entirely in electricity supply, when in the case of all other industries that element of demand takes its proper place. In the case of tramway supply, speaking broadly and roughly, the market price of the supply from a combined station will necessarily be somewhat lower than the price at which the tramway company can generate for itself. It must be something better, looking at the matter from a commercial point of view, in order to induce the tramway company to take the supply from the combined station to the advantage of the combined station, and probably to the advantage of both. Then if there is a profit upon the works, and it is not desired to make any other use of the profit except in the reduction of price, I contend that the scientific way of reducing the price is to take a percentage off the market price of the commodity supplied, whether it be heat, light, power, fixed or locomotive. It does not matter that electricity is being supplied. What is really being sold is a supply of light, power, or heat. When I last spoke on this subject in this room I gave an instance from an outside industry, mentioning steamship companies and railway companies, and I asked whether it was equitable that the railway company should charge 50 per cent. more for the transport of a box of brass castings than the transport of a box of iron castings of the same size and weight. It costs them the same to transport both, but they charge a different rate. And so it is throughout industry, because under the law of supply and demand services have each their own market value. We cannot get away from that, and the attempt to get away from it in electricity supply is, I think, leading the commercial side of the industry into a very awkward position. Take another quite commonplace instance, the case of a theatre. The cost of the performance to the people seated in the different seats of the theatre is practically the same, and yet those seats are carefully arranged both as to number and price, in accordance with the law of supply and demand, and in that way the largest aggregate gain is made by everybody concerned. In order to crystallise the points I have put forward to-night, I have drafted a postulate, a definition, and a law, with which I will conclude. The postulated principle is, that within the limits of practicability (it is impossible to carry out this principle in every direction) price should be fixed as between different classes of consumers as nearly as possible in propor-

tion to the market prices of the services rendered. The definition is this: "Market price" is the price determined by the law of supply and demand, excluding any monopolist element. It is not determined by the utility of the service rendered, nor by the cost of rendering that service, but it is influenced by both, and is a resultant of both. The law is this: When prices are adjusted in accordance with the above postulate, it will follow that the largest aggregate gain will accrue to the community concerned, and the distribution of that gain will be the most equitable possible. I submit that these dogmas are scientifically unassailable, and embody the only rational principle to adopt in fixing methods of charging. Mr. Cowan.

Mr. A. H. SHAW: I do not quite agree with the author's deductions, which appear to be taken chiefly from two large undertakings. In looking through the output of the sixty-five or more authorities who take a supply from a combined station, I find that fully half of them take less than 1 million units per annum. Now what is applicable to a large station taking 10 or 15 million units per annum is not, I submit, applicable to a small station supplying considerably under 1 million units per annum. In a small station, for instance, a station like the one with which I am connected at Ilford, supplying some twenty cars, with an average of twelve cars out on the road, one small set is sufficient to supply all the current required. But the load on that set varies sometimes from no load to 25 per cent. overload. It is very plain, therefore, that the units generated by a set under those conditions cost very much more in coal alone than the units generated by a set supplying current for power or lighting running at its most economical point. Another point with regard to such a set is that the wear and tear on it is considerably heavier than on a set running under a steady power or lighting load. I have found from experience that the maintenance and the cost of repairs on sets running chiefly or entirely on traction are very much heavier than on sets kept for lighting only. Although, no doubt, in some cases small stations have charged considerably more than the actual cost, or more than they possibly should have done, in order to assist the combined undertaking, that is by no means always the case. In my own case, when our tramways were first started, my Council seriously took the matter into consideration, and held several meetings to discuss the subject of the right charge to make. They were informed at that time that it was illegal for one department of the Council to make a profit out of another department, and therefore they determined not to fix any rate of charge, but to wait until the end of each completed year, and then to try and get as near as possible to the actual cost of the supply. In the last two years we have fixed the rate at 1⅛d., which I think for an undertaking supplying 800,000 units is a very low rate indeed, although it is not low enough to satisfy our Tramway Committee. As we are supplying certain relatively large consumers of power at 1d., the Tramways Committee think they most certainly ought to have the current at that figure. In getting out this price we have to some Mr. Shaw

Mr. Shaw. extent followed the lines which the author lays down; that is, we have only taken the proportion of the plant that has been used for the traction on the maximum demand. We have taken the proportion of capital charges, rent, rates, and taxes allocated to that portion of our total plant, and also the proportion of the wages and the other charges, and we have also taken the average of the running costs. The author states that by including the running costs of the whole station the price will be brought down. I do not agree with that so far as the coal is concerned. From what I have stated just now, I consider that the amount of coal per unit taken by the current supplied for the traction is higher than the amount of coal per unit on the total supply. Therefore the lighting and the power get the benefit of that instead of the tramways.

The President. The PRESIDENT: Can you give us the load factor of the private consumer who gets the current at 1d., and the load factor of the Tramway Committee which gets it at $1\frac{1}{8}$d.?

Mr. Shaw. Mr. SHAW: The load factor in the case of the traction is about 26; and in the case of the private consumers (we only have two consumers at 1d.), as far as I have been able to ascertain, is 20 to 25. As a very great deal in my opinion depends upon the total amount of current supplied, I think the tables in the paper would have been of very much more value if there had been an additional column stating the number of units taken by each of the authorities. The prices are given, but there is nothing to show the total number of units taken in each case.

Mr. Wordingham. Mr. C. H. WORDINGHAM: The subject of combined or separate stations is one around which a fierce controversy raged some twelve or fourteen years ago, and I was one of those who took the view that combined stations were usually correct. Manchester has been referred to in this paper, and its policy rather strongly criticised; and therefore I should like to say that I was directly responsible for that city adopting a combined station, and a very hard fight I had to overcome the ambitious Tramways Committee, who had many reasons for wanting their own station, not the least cogent, I think, being that they felt it lent them a good deal of prestige actually to generate energy as well as the Electric Lighting Committee, of which they were very jealous. I feel very strongly indeed that this, like most engineering questions, is one which must be approached on broad lines and be settled on broad principles, and no policy of universal application can be laid down. It must depend very much upon circumstances; for example, if there is a very extensive tramway system and a very small lighting system, the result of combining the two must be very different from what it is when the tramway system is comparatively small and the lighting system very large. There is one point, moreover, that should not be overlooked, viz., the consideration of whether both undertakings are in the hands of one authority or not. If they are, I do not think there can be the least doubt that, looked at from the broad point of view of the municipality or other authority, there must be a saving in

Mr. Wordingham.

the total cost to the body owning them by combining the two. If, on the other hand, the one concern is in the hands of a company and the other in the hands of the municipality, then under certain conditions I think it may be cheaper for the owners of the tramway undertaking to generate their own energy, because obviously if a generating station with a good load factor, such as many tramway stations have, be made to take an additional load with a poor load factor, it can hardly be expected to improve the average load factor; it must send it down. Therefore, unless there be a great increase in the scale of operations of the station, so that much larger units of plant can be employed, the cost will probably increase. But I believe these cases are few and far between, and in nearly all cases it does pay to combine—that is, generating becomes much cheaper by combining the two undertakings; in fact, to admit the contrary is to upset all recent ideas on the subject of power supply. Everybody harps upon the desirability of increasing the scale of operations, and adding together the different loads, and if it is proper policy to combine similar loads for the sake of increasing the scale of operations, how much more desirable must it be to combine dissimilar loads. Leaving that general question we come to the allocation of the costs of the Manchester supply. I have not gone into every detail as to fixed and standing charges and what not, but I see the Manchester Corporation still adhere to the system which I so strongly advocated—namely, that the Hopkinson principle should be adopted for tramways as for every other sort of supply, and that the Tramways Committee should pay according to the maximum demand a fixed sum per annum plus a sum for running charges. The necessity of including a portion of the coal in the standing charges has been attacked. As on a recent occasion, I would again refer those who wish to understand the subject to Dr. Hopkinson's original paper,* where it is shown most clearly that a portion of the coal must be a standing charge, not because, as Mr. Yerbury seems to think, it is assumed that the fires must be banked up for some possible peak load, but because boilers, steam pipes, cylinders, and everything else are constantly radiating heat, and coal must necessarily be burned to make up for that radiation. That is a standing charge, for it does not depend on the load; and these radiation losses are far heavier than central station engineers appreciate. In my opinion, it is unassailable that those are standing charges. With regard to the price that should be charged for energy for tramways as compared with energy for other purposes, I do not agree that supply authorities should discriminate between the different purposes for which energy is used. I strongly believe that each class of consumer, whether for lighting, power, or traction, should pay the proportion of the actual cost that such consumer costs to supply. Having been paid the cost, however, I do think the station may quite properly make different rates of profit on the different classes of consumer. If they can get a consumer who gives a very large turnover they are justified in charging a smaller rate of profit in order to secure

* *Transactions o the Junior Engineering Society*, vol. 3, pp. 1–14, 1892

Mr. Wordingham. him than to a consumer who gives only a small turnover. On that principle one may, I think, discriminate in the price, but not because, as Mr. Cowan says, there is a different market value. I cannot follow Mr. Cowan in that at all.

Mr. Bond. Mr. W. G. BOND: I regret that the discussion has resolved itself into a domestic quarrel between two members of the municipal family as to what share of the total cost each member of the family should bear. The subject interests me very greatly, but to some extent from the point of view of the outside buyer. What is urgently required at the present time is not so much a detailed scheme of charging for a tramway supply as a broad general principle to apply to all customers. I was hoping that the discussion might perhaps evolve some broad principle of this kind. A large number of municipal stations depend, for a large portion of their profit, upon supplying tramway companies, and the agreements made with the latter are generally to the effect that in default of agreement the price shall be fixed by arbitration. Of course, the company and the municipality never agree, and the first price has invariably been fixed by an arbitrator. It is quite excusable, I think, that in the early days the arbitrators should have worked by rule of thumb, but in these agreements there is also usually a clause to the effect that the price shall be revised every five or seven years, and it is on account of these revisions which are now taking place every year in some town or other that I was hoping the discussion would, at any rate, show some general agreement as to the principle upon which a tramway company should be charged for its supply. On page 596 of the author's paper there is something in the nature of a broad principle which I personally should be prepared to agree to. Mr. Yerbury there says, "It has been suggested by many tramway managers that under the same municipality the Tramways Department should not be charged a higher price per unit than the estimated total cost of production from a separate station." I think it is a most important matter for the tramway industry that there should be some general principle laid down by which the arbitrator should consent to be guided. At the present moment there is no broad recognised principle.

We have heard a good deal this evening about the advantage of combined lighting and traction stations. I do not quite know whom they benefit. They are not of much advantage to tramway companies enjoying a municipal supply. In several cases of which I have some personal knowledge it is perfectly certain that the tramway company could get its current at a lower price if it were allowed to build even a small station and supply itself (all proper allowances being made for capital charges and profit) than is the case at present. I am in general agreement with the author's summary at the end of the paper, even to the extent of agreeing that some sort of "profit" should be allowed, though I am a little doubtful if it should be as much as 5 per cent., because in the case of a municipal supply the unit is already debited with 3 per cent. or more for interest, and therefore if the tramway department in addition be allowed 5 per cent. profit, it really assumes

the position of a company making 8 per cent. over and above costs, renewals, and depreciation. My own idea of a broad general principle is that the charge made for a tramway supply should be such as would be made if the supply were given from a pure traction station, not from a mixed station hampered with a number of relatively unprofitable light or power customers, but from a station supplying a tramway and nothing more. I may be told that by so doing I shall lose the hope of future reductions due to the growth of the electricity undertaking as a whole, but I do not consider that would be very serious. Mr. Bond.

Mr. C. E. C. SHAWFIELD: I am responsible for the running of a combined station, and have been guilty of the sin of charging the Tramways Committee more than the ordinary power consumers. But, nevertheless, I do not feel in the least penitent. I think Mr. Yerbury has entirely missed the point in his paper when he states, or appears to state, that tramways should be charged in all cases at least as low a rate as ordinary power consumers. The load factor of a tramway is by no means as good as it is supposed to be. I know that in my own district the average number of cars running during the day is about twenty-five. Towards evening in the winter it increases to forty or forty-five, just at the time when the peak load of the other consumers is on; and not only that, but every car stops at every stopping-place, and has to be started up again from rest. Most tramway engineers and central station engineers will recognise what that means as an addition to one's peak load between four and six o'clock in the winter months. There is another question which must be taken into account in determining the charges as between the tramway load and the ordinary power load. The tramway undertakings in this country which are supplied from combined stations have been running over quite a large number of years. I suppose the Wolverhampton undertaking may be taken as a fairly average line; it has been running now since about 1902. At that time the cost of plant was very considerably more than it is now. Mr. Yerbury says in his paper that it is possible to get plant for low-tension direct supply, including generating plant and buildings, at not more than £35 per kilowatt. In 1900–1901, when purchasing the plant of the Wolverhampton Tramways in accordance with the requirements of the Tramways Committee, and purchasing according to the lowest tender received in the open market, the total cost of buildings, boilers, generators, cables, etc., came out at nearly £100 per kilowatt. Again, it must be remembered that steam consumptions in those days were very different from what they are now. It was a fairly good result then on a station supplying, say, 1½ to 2 million units per annum for tramway purposes to have sets giving 27·5 lbs. of steam per kilowatt-hour. But within the last two years I have built an additional power station, 3-phase, E.H.T. supply, in which the capital cost per kilowatt of buildings, boilers, generating plant, switchboard, mains, everything complete, comes out to almost exactly £20 per kilowatt, and the average steam consumption is about 18 lbs. per Mr. Shawfield.

Mr. Shawfield. kilowatt-hour. If Mr. Yerbury wants to revise my charges to the Tramways Committee on the basis of my present costs to power consumers, he must say then that I must be prepared to scrap the plant which I bought for the Tramways Committee seven years ago. But, if he says that, where does his allowance for depreciation and obsolescence come in? Since that plant was bought for the requirements of the tramways undertaking, it has to be run for the tramways supply, and it is fairly obvious that the cost of supplying them is higher than the cost of supplying those large power consumers whom I have connected up within the last two years, and who are supplied from cheap modern plant which is very much more economical in its generation of electricity.

Mr. Holmes. Mr. A. BROMLEY HOLMES (*communicated*): The existence of combined stations is only justified if each service is benefited by the combination. That such combination should be beneficial is obvious, provided that a site can be found equally suitable as the centre of distribution of energy for the tramway and lighting services. Granted this condition, there can be no advantage in building two stations instead of one, or in installing two isolated sets of plant, or dividing the labour and supervision. It is evident that both capital charges and working costs should be reduced by combination. I agree with Mr. Yerbury that the advantages of low-pressure distribution, especially for the tramway service, are sometimes overlooked, but, on the other hand, to be able to run both services at the same time from one large set of generating plant instead of from two smaller and separate sets is in favour of a high-pressure system of generation. When the district supplied is a large one a high-pressure system of distribution becomes a necessity. Where the tramway and lighting services are already in partnership in a combined generating station the question is not at what cost the tramway supply could be furnished from a new station with new plant bought at present prices, but rather what the fair division of costs is under the existing conditions of joint ownership. I join Mr. Yerbury in strongly condemning the sale of electrical energy to any consumer, however large, at or below cost price on bargains which are commercially unsound when the price charged does not include a fair proportion of all the charges which ought to be borne by every consumer. Such unfairly preferential treatment can only be given at the cost of other consumers.

The underground cables for lighting and power in a combined system must always largely exceed the similar cables used for the tramway supply, and Mr. Yerbury's suggestion to burden the tramway department with a separate staff to lay and maintain such cables would appear to be a mistaken policy. Mr. Yerbury's views as to the general accuracy of supply meters will accord with those of engineers having experience in such matters. Deductions as to the fairness or otherwise of prices charged for the tramway service cannot safely be drawn from grouping together sixty-five combined stations, as in Table I. Local conditions vary widely, as also do the items covered

by the prices in the various localities. In any large tramway undertaking the works costs (fuel, water, oil, etc., labour and repairs) for the tramway service will, with coal at normal prices, not exceed, say, 0·4d. per unit, but as regards the other items included in the price charged there may be very wide variations. At Liverpool the Corporation have decided that the price charged for the energy supplied to tramways, which price varies automatically with the price of fuel, must include the following items:— Mr. Holmes.

1. Cost of generation and distribution.
2. Repairs and maintenance (including mains for tramways).
3. Rents, rates, and taxes.
4. Management and general expenses.
5. Charges for sinking fund and interest on capital.
6. Contribution to renewal and reserve funds.

A price which has to cover all the above items can only reasonably be compared with those of other undertakings which include exactly similar charges. The last item, viz., contribution to renewal and reserve fund, will naturally vary with the special conditions of each undertaking and with the margin of safety for the commercial future of the undertaking which it is considered desirable to provide.

Discussion at Sheffield, January 26, 1910.

Mr. A. J. Cridge: Before I proceed to make any remarks upon the paper I should like to say on behalf of my chief, Mr. Fedden, that if in Sheffield the tramways and electric supply undertakings had been combined, and the profit which the tramways department has given to the relief of rates had been applied to the betterment of the financial position of the joint undertaking—by which is meant the reduction of the enormous over-capitalisation of the electric supply department—it would have been better for the ratepayers as a whole. Cheap power and cheap tram rides promote employment and trade in this city, and are as great a boon as low rates. The Corporation's undertakings are really one business, and every effort should be used to make all parts of it financially sound. Those are Mr. Fedden's views on this subject, and I venture to express my cordial agreement with them. Now Mr. Yerbury starts with aspirations after equity and an air of impartiality, but we do not have to look very far into his paper to observe the one-sided views of the tramways official. On page 586 he suggests that the charges to tramways departments are usually too high, and in the case of combined stations I think that is often the case. The peaks on the two kinds of load do not occur at the same time. In the morning there is a tramway load when the men go to work, then when the works are open there is a power load; this goes off at dinner-time, and there is a tramway load for taking people home and bringing them back; then comes the afternoon power load and the office lighting Mr. Cridge

Mr. Cridge load, and when these go there comes the 6 o'clock tramway load; then the theatres come on, and finally the people go home from the theatres. Thus the effect of a tramway supply would be to flatten out the electric supply load, and so conduce to economy in running. Mr. Yerbury thinks that if we make a profit on the sale of cheap units we should apply this profit to the reduction of the charges for lighting. Well, we do to some extent. Perhaps he is not aware that for long-hour use in the daytime consumers can have a discount of 50 per cent. from the ordinary price of 4d. per unit. I think, too, he should have remembered that his own car-sheds at Tinsley are supplied at 1½d. per unit. It would be impossible for the electric supply department to supply 13 million units at 2,000 volts, 2-phase, at the Kelham Island switchboard at 0·55d. per unit. When Mr. Yerbury spoke of the unfairly low prices sometimes charged for power, I was aware that he was referring to Sheffield. Now, at the time when the undertaking was purchased by the Corporation, a large sum was paid for goodwill and other non-tangible assets. The charges on the capital involved have to be paid if there is not a single motor on the mains. If by investing new capital a profitable return can be obtained, I say that it is a business proposition so to invest it. Is it fair to charge later consumers upon capital which is of no value for the purposes of their supply? I think not, and Mr. Yerbury says in his paper that a tramways undertaking should only be debited with the capital charges incurred on its behalf. I take that proposition and apply it to the sale of electricity for power, and I would like to apply it to new lighting consumers as well. Mr. Rider once said, "The only true basis on which to charge is the load-factor basis tempered by the diversity factor. It is all very well to say it is impossible to get custom if one attempts to charge individual customers on the maximum demand or on the load-factor basis. Difficulties may be met with in that way, but they can partly be got over by treating the consumers as a class and by applying the maximum demand principle to the fixing of the price. A tramways undertaking is a class by itself, apart from other kinds of power supply, and I feel justified in mentioning a lower price than is ordinarily available for users of power." I agree with most of the points in the summary, but I think the suggested profit of 3 to 5 per cent. on running charges alone is very thin. If it is to be so little, why not supply at cost and leave the money which would be profit to the electric supply department in the bank as a special fund? It may be set aside for depreciation, renewals, obsolescence, surplus, or any other purpose, and instead of being applied in relief of rates, it will become available for the betterment of the business. I was rather surprised to see that Mr. Yerbury's load curves were so smooth. I was certainly under the impression when I visited Kelham Island that there were much more pronounced peaks to be observed.

Mr. Acland. Mr. R. L. ACLAND: It is very desirable that some equitable basis should be arrived at on which the charges to the tramways department for the supply of current may be assessed. We certainly often hear

the tramway and electrical departments talking of each other in a rather uncomplimentary manner, and it would be much better if some arrangement could be arrived at which would suit all. I think that some of the figures in the paper apply very much more to the larger undertakings with good load factors than to the smaller systems, such as the one under my charge at Chesterfield, where the tramway peak comes, particularly on Saturday night, right on the top of the lighting load, and thus considerably reduces the station load factor. I have some figures showing that the load factor of the stationary motors is about 13 per cent., and the tramways about 14 per cent. Taking the author's figures as a suggestion for the calculation of the price to be charged, I find that it works out in our case at 1·1d. per unit, as against 1·25d. charged by the lighting department to the tramways department. The author speaks of the maximum demand system as being very largely used on the lighting side. I should think if he has had very much experience of lighting supply he will find it is something to be got rid of, and some of those concerned, I am sure, would prefer going over to the flat rate system of charging. On small undertakings the curves are very much more "peaky" than those given in the paper. I am of the opinion that if this matter is taken up and a joint conference arranged between the Municipal Tramways Association and the Municipal Electrical Association, with the idea of arriving at an unbiased conclusion as to the basis on which the charges should be made, it would do away with the unpleasantness that exists between the electricity supply and the tramways departments in a good many cases. I am sure we all appreciate the results achieved in the standardising of accounts for the lighting and the tramways departments by the associations I have mentioned. Mr. Acland

Mr. E. J. MARSH: There is urgent need of some uniform system capable of adjustment for dealing with extraordinary requirements where the supply is of a very variable character, and such a system would be gain to both departments. On page 594 an important point is mentioned in the "valuation asset" of the undertaking after the capital has been fully paid. Recently the Local Government Board have reduced the period of repayment of loans for new extensions from thirty years to twenty, so that in twenty years the old plant and the new will be practically free from capital charges, which leaves valuable property at the end of that period as an asset belonging to the tramways department, even allowing liberally for obsolescence. Another point often not appreciated in the case of separate stations is the fact that the staff, whose wages and salaries are included in the cost per unit, is available for other work which in the case of a combined station is done by the staff of the tramways department and charged under another item. This is shown by the figures in Table I., where there appears to be no appreciable difference between the tramways departments which maintain their own cables and those where the cables are maintained by the electric supply department for the inclusive price charged to the tramways authority. Mr. Marsh.

Councillor Fenton.

COUNCILLOR FENTON: Looking at the matter from a layman's point of view, there are one or two points that appeal to me very considerably. On page 586, where the author refers to the question as to whether some consumers will only pay exactly the total cost price of generating and also the large power consumer who can only be obtained by offering a supply at less than the total cost price, I think that appeals very much to the ordinary user, and it is a question that has been generally discussed by people who use light, as to whether they are not paying for some of the deficiencies which some of these users ought to be paying for; and some of us rather fancy that we are paying more than we ought to pay if these charges were equitably based. Mr. Cridge in referring to that matter suggests that one should not put on these power charges the amount loaded up for the old capital. But if not to the power consumers, why to the private users of electric light? I do not see any reason for letting the one off and putting it on to the other; it is not equitable. You can understand a company doing that, but I do not think a municipality ought to do it. Taking the paper generally, I think it is an advantage that Mr. Yerbury can look at the subject from a very impartial point of view; he is not buying electricity from any one else, and is producing it as cheaply as any one in the country. With regard to Mr. Cridge's remarks, he mentioned Mr. Fedden's opinion that we ought to give cheap rides and not relieve the rates to a great extent. It appears to me that in many cities it is impossible to give the cheap rides because of the high cost of electrical energy, and it does seem an extraordinary thing in places like Manchester and Bradford that they should charge such a high price per unit to the Tramway Department as compared with what they charge to the private users. The fact of the matter is this, they know the tramways are a source of great revenue, and they want to turn the lighting department into a paying department. I think every concern should be put on its own commercial basis and let each department pay its own way. Mr. Cridge made us an offer and said they would be willing to supply us with high-tension 2-phase current at 0·55d. per unit, but I do not think it would pay the department to take it even at that price after allowing for transmission and conversion losses. We are better off as we are at present. It will never pay the tramways department to take energy from another department. At any rate, I should want a lot of figures to make me alter my opinion. I think the paper has elicited some interesting discussion. I have tried to pick holes in the paper as a layman, but I think it is based on a reasonable basis for dealing with these charges. Fortunately it does not affect Sheffield.

Mr. Wardale.

MR. W. T. WARDALE: I think the discussion centres on the question, "Why do lighting and power stations charge tramway departments such high rates for current, when tramway companies with separate stations can, and do, generate so much cheaper for themselves?" I agree with Mr. Fenton that in most towns the lighting

and power supply authorities have the tramways department at a disadvantage, the latter having no alternative supply to turn to. This being the case, the policy of the lighting stations has been to obtain as high a rate as the tramway profits will allow for the current supplied to them. Mr. Cridge said that they could supply power to the tramways at 0·55d. per unit, with high-tension 2-phase current, but I think the question is not whether they are able to do so, but whether they would do so if the tramways were absolutely dependent on them for current? Experience tends to support my view that they would not. The principle that because one department is making a profit it should be overcharged to cover up the deficit on another department is an unsound one. In a lighting and power supply the charges for power have to be kept down, simply because the large private plant and the gas engine are most strenuous rivals to the station, and if the energy is not sold at prices at which it is practically given away, many of the large consumers will not consider taking it. Regarding the capital which Mr. Cridge alluded to, I think he should consider it simply as one of the expenses of establishing the business; if they bought the business from the old company at an inflated value, that is their fault for making so bad a bargain. It is hardly fair to suggest that the old consumers who helped to establish the business, and who stood by them in the days when they were gradually building up a load, should continue paying at a high rate for their current; and these high rates to the lighting consumers cannot be justified on the lines indicated. I do not think it would pay the tramways to take current at 0·55d. per unit, as Mr. Cridge suggests. In my own case, we are generating as cheaply as that ourselves, and naturally hope to do better in the future. Mr. Wardale.

Mr. I. F. Fawcett: Regarding the profits which the author suggests tramways should pay lighting departments, it seems to me that the fixed charges would come to a considerable amount compared with the running costs, and if you fix the profits by merely paying 3 or 5 per cent. on the running costs, you will only be really paying $1\frac{1}{2}$ to 2 per cent. on the total cost. As a certain amount of plant must be installed to meet the tramway costs, I do not think that the profit of 3 or 5 per cent. on the running costs would give a fair margin of profit. I may be slightly wrong, but that seems to bring the figure rather low, and the margin of profit would not be sufficient to make anybody very keen on a combined station. The figures given in the tables vary to an enormous extent, but there does not seem to be any just reason for this variation, and it appears to me that it shows a lack of combination on the part of the central station engineers and the tramways engineers that this subject has not been thoroughly thrashed out before. Mr. Fawcett.

Mr. H. Dickinson: The author, on page 584, says that the maximum demand principle is the fairest system of charging, and that the majority of municipal supply tariffs are based on this system, whereby all consumers are supplied on the same terms. We do not supply all consumers on the same terms, and that is not the maximum demand system; certain classes of consumers are charged on the same Mr. Dickinson.

Mr. Dickinson.

terms. If you examine the supply terms in the electrical journals you will find that there are terms for lighting, power, street lighting, and traction, so that there appears to be a mistake here. The author argues that every one ought to be charged on the same basis, but if you turn to the following page you will find that he immediately claims the preference for the tramways department. He also remarks on page 584: "It may be said that the generation of electricity is the same, no matter what use is made of it." I quite disagree with this statement, because I maintain that it is cheaper to provide for power load than for a lighting load of the same load factor. In the former case you provide the requisite boilers and labour, etc., for a practically known load from day to day, but for the lighting load you have to provide spare boilers and labour to meet the fluctuating peaks, which come on at any time, due to thunder showers, fogs, etc. There has been a great deal said as to equitable charges, but the question is, What is an equitable charge for lighting? No one, so far as I am aware, has defined this point. Surely it is legitimate to charge what a consumer is prepared to pay. Taking into consideration the competition from other illuminants, there is no doubt at all that supply undertakings get a higher price and a higher profit for lighting than they do for power, for the simple reason that they are in less competition in lighting. A person having a private plant cannot, generally speaking, produce for himself so advantageously for lighting as for power, on account of the very fluctuating load and poor load factor for lighting as compared with power. With lighting, the summer requirements are very small, but for power the requirements should vary very little, winter or summer. I consider that we are perfectly justified in charging the lighting user a higher price, because we can get it, and competition governs the price we can obtain. On page 586 the author remarks that these extra charges are only imposed on certain customers, notably on tramway authorities. I say it is a question of competition pure and simple, and if we are going to bring down the charge to the maximum on the class of consumer that we have to compete for so keenly, we shall soon lose all the margin of profit that we are getting at present on lighting, and I am afraid that it would ruin the business. The charges vary accordingly to what the customer is prepared to pay, and we are perfectly justified in getting as much as we can. I am not arguing that the author's figures or contentions are not correct; I believe myself that in certain cases the supply authorities are charging for their supply a high price to tramway authorities, but I think that is only part of the argument, and I maintain that a very good case could be made out for the lighting people who are charging the high price, because they are able to develop a power business that is of benefit to the town; it tends to bring people to the town where the cheap power supply is; and I maintain that ultimately the combined station will be able to produce at a cheaper rate because of the power business. The lighting and power business is growing much quicker than the tramway business. The greater the development the lower the price will become, and ultimately the combined

station will be able to supply energy to the tramway undertakings cheaper than the tramway undertaking could supply itself. Under these conditions, if the lighting authorities charge the higher price, it makes no difference, for the money has not gone out of the Corporation's pockets; it has only been transferred from one pocket to the other, for the town has got the profit either in the lighting or the tramways department, and it has also got this large power business, which should be of great benefit to the town. The author shows a number of charts which he mentions indicate practically a steady load. I hardly think that is correct, for if you take curve A, which shows an average of 4,000 amperes, and compare it with the one on the next page, it will be seen that the latter goes up from 4,000 to 6,000 amperes on a Bank Holiday, which is an increase of 50 per cent. It is well to bear in mind, however, that Bank Holidays only come occasionally, but if you take these holidays and the days immediately before and after—say ten per annum—you will get a maximum on these days of 50 per cent. above the normal, so that I do not think it is fair to say that the tramway load is anything like a non-fluctuating load. Mr. Dickinson.

Mr. W. M. ROGERSON: Although I am connected with both lighting and tramway undertakings, I agree in the main with the author. There is no doubt that a large number of towns are overcharged in the tramways department, and it is necessary to look into the reasons for this. In the first place, it will be found that in a large number of these towns electric lighting came first, and small stations were put down because it was never expected that the large outputs of the present day would come to pass; so that in a very large number of cases the generating stations were put down in the centre of the town with no water supply, or possibly only a small brook available for condensing purposes; consequently in such cases the works cost in a combined station cannot compete with a tramways station pure and simple, which was put down probably some six or seven years later, and had thus the benefit of the lighting experience. I cannot see very much difficulty in allocating the equitable charges, because, after all, even if the works cost is high in a combined station, that can, of course, be charged to the tramways department *pro rata* to other customers. We in Halifax charge at a fairly low rate—$1\frac{1}{16}$d. per unit. We also have a power charge varying according to the number of units consumed per horse-power per quarter from 2d. down to $\frac{7}{8}$d. per unit. These charges were got out some four years ago, and at the same time we also compared them with the tramway charges, and found that the actual price charged for tramway purposes was less than it would have been had the charge been at our ordinary power rates. At that time I was not in charge of the tramways department. When I received a copy of this paper I again calculated the price which would be charged to tramways upon our power scale and also upon Mr. Yerbury's suggestion, and I find that, taking last year, the average price we should have charged on our own scale to the tramways would have been $1\frac{1}{4}$d. per unit; as a matter of fact they are paying $1\frac{1}{16}$d., so Mr. Rogerson.

Mr. Rogerson. that they are really charged lower than our ordinary scale. It is rather curious that in February, 1908, the Borough Accountant and myself went into this matter of charges, and we suggested practically the same method that Mr. Yerbury adopts in his paper—that is to say, we separated the capital charges which are distinctly applicable to either tramways or lighting—*i.e.*, feeders, etc. Then we found out the demand on each system and the capital charges which were common to both, such as buildings, plant, etc., and divided the cost of these *pro rata* to the demand, and took the works costs as they then stood, plus interest and sinking fund, *pro rata* to the capital outlay as estimated for each undertaking, and we found that if we charged in that manner then the charge for tramways supply would be 1·32d. per unit, taking simply the works costs as a running charge as against $1\frac{1}{16}$d., which is the actual price paid. One must, I think, allow something to the tramways, for there is no doubt they are a valuable asset to a purely lighting station. I must congratulate the author on his load curve. Perhaps in Sheffield there are no very heavy gradients, but a very quick service of cars. In Halifax the gradients are very heavy, the steepest being 1 in 9·5, and every route from the centre of the town is uphill with one exception, the easiest gradient being 1 in 12 ; and we have no less than thirteen different routes going out of the town. Of course, the hills make a big difference in Halifax, as well as the number of cars per mile, which considerably affect the load factor. I see he has our load factor at 20 per cent. I make it 18 per cent. At any rate, it is a fact that the load factor on the lighting and power supply is a trifle higher than on the tramway supply, so that really taking the price on the load factor the electricity department ought to be receiving rather less per unit on the average for lighting and power than they are per unit for tramway purposes. As a matter of fact, our average price obtained comes out at 1·8d. per unit for lighting and power, while for tramways it is $1\frac{1}{16}$d. per unit. I should like to see some arrangement come to between the Municipal Tramways and the Municipal Electrical Association with regard to these charges, but at the same time, when this matter is discussed, care will have to be taken that every consideration is given to conditions, because these make an enormous difference as to the price that can be charged without bearing unfairly on either one or other of the undertakings.

Mr. King. Mr. W. N. Y. KING (*communicated*): Considering the fact that a high load factor and a demand for a large number of units conduce to the cheap production of electrical energy, it is reasonable to expect that a tramways system (of any but the smallest size) should be charged on the lowest scale existing in any case ; for it compares more favourably than any ordinary lighting or power consumer in respect of the two items above mentioned. However, from the tables given this does not seem to be the case, and any information which will explain or otherwise lead to the extinction of this discrepancy will be highly valuable. To take up a point in detail : in Table V. are mentioned seventeen systems purchasing over 2 million units per annum ; if these

systems are compared with one another in respect of the excess of the price per unit charged to tramways (see table appended) over the total works costs (including rent, rates, taxes, management, insurance, etc., but not interest, sinking fund, and depreciation), they vary between very wide limits, and in some cases the excess, which presumably is to supply interest, sinking fund, and depreciation, is so great that it does not appear to be equitable, to a consumer who brings the advantages of high load factor, large total demand, and simple metering and book-keeping. On the other hand, it is only fair when estimating a price to allow for such changes as are liable to occur Mr. King.

Locality.	A Total Works. Costs.	B Price Charged to Trams.	Ratio B/A.	Per Cent. Excess of B over A.	Combined Load Factor per Cent.
	d.	d.			
Birmingham...	0·72	1·27	1·760	76·0	20·36
Blackburn ...	0·90	1·40	1·560	56·0	18·49
Bolton ...	0·58	1·10	1·900	90·0	24·75
Bradford ...	0·65	1·12	1·720	72·0	28·29
Burnley ...	0·85	1·34	1·580	58·0	22·75
Croydon ...	1·11	1·78	1·600	60·0	20·93
Dundee ...	1·15	1·25	1·090	9·0	19·77
Halifax ...	0·96	1·06	1·105	10·5	22·17
Liverpool ...	0·81	1·12	1·380	38·0	23·36
Manchester ...	0·66	1·04	1·580	58·0	24·55
Nottingham ...	0·99	1·25	1·260	26·0	20·48
Oldham ...	0·89	1·50	1·680	68·0	21·73
Rochdale ...	0·76	1·14	1·500	50·0	22·17
Salford ...	0·65	1·26	1·940	94·0	27·66
Stalybridge ...	0·37	1·00	2·700	170·0	26·18
West Ham ...	0·52	0·99	1·920	92·0	29·05
Wigan ...	0·98	1·41	1·440	44·0	18·35

The mean excess of B over A is 63 per cent.

in the cost of coal, etc., and the benefit of any doubt should be on the side of the supplier, and the sale is his main if not sole source of revenue, and a very slight decrease in receipts would involve a much more serious loss than a corresponding over-estimate to users of the energy; as in the latter case, in all probability the cost of energy is a much smaller proportion of the working expenses.

Discussion at Manchester, January 25, 1910.

Mr. S. L. Pearce: I am glad to note that the author is not entirely in favour of separate tramway stations for every possible locality. I rather gathered, when he delivered an address some few years ago as Chairman of the Leeds Local Section, that that was the attitude he took up. Mr. Yerbury's wish to bring about a generally accepted method of charging for traction supplies from combined stations is Mr. Pearce.

Mr. Pearce. a very laudable one, but I venture to think that he makes a serious mistake in supposing that the costs as declared by self-contained undertakings and published in the "Standard Form of Tramway Accounts" are necessarily correct, and that the charges made in combined undertakings invariably err against traction. I do not criticise for one moment the "Standard Form of Tramway Accounts." They may be quite fair and proper, and the best that can be devised, but they do not prevent absurd comparisons being drawn between the two classes of undertakings. Mr. Yerbury draws attention in the footnotes appended to his tables to the variable practice obtaining in different towns as regards the apportionment of some of the capital charges. He omits to point out, however, that comparisons in a good many of these cases have frequently been drawn between stations, in which a direct low-pressure current delivered from the sub-stations within a few yards of the tramway routes has been compared in cost with an alternating high-pressure current metered at the generating station busbars, without making any allowance either for works consumption or for losses in transmission, conversion, and distribution. To compare cases on an unequal footing like this is absurd. In Table V. I do not think the author is fair, because if you will look at that table giving the maximum and minimum charges of the two classes, you will see that he is comparing towns in which, owing to the different systems of supply, sweeping adjustments should be necessary in any proper comparison.

I should like to enlarge on the question of the tramway accounts. Take the treatment of the item for rates and rents in connection with the distributing system under the "Standard Form of Tramway Accounts." It is quite possible to charge those items, and in some cases they are charged against the tramway general operating costs. Again, differences of policy with regard to depreciation make an enormous difference in the accounts, or in the actual costs of production as the case may be. Where the provision is on a liberal scale, this amount can, under the "Standard Form," be treated not as a cost, but purely as an appropriation of profits, and in consequence it does not figure in the actual cost or price per unit. In the cases of combined undertakings, the due proportions of such amounts as the above are all merged in the charges against the tramways departments, and are of sheer necessity part of the price quoted per unit. I have said sufficient to show a very great need for adjustments being made between accounts of the two classes of undertakings in comparing the prices of cost of production on the one hand and selling prices on the other. In the case of Manchester, my department tried to get their figures down to a comparable basis with both Sheffield and Glasgow, and the work found necessary would deter any one from generalising on the mere strength of published data, seeing that the bases of those data are invariably dissimilar. It may be of interest to the members if I refer to the results of these comparisons. Taking Sheffield, the published figure is 0·668d. per unit generated. Through the courtesy

of Mr. Fearnley, the Sheffield General Manager, we were able to obtain data not found in their accounts. Sheffield, in their 0·668d., omit several items. First, they omit all question of rates on ducts and cable work; secondly, they omit income tax; and finally, there is the question of an adjustment to be made for additional units lost in transmission, as compared with the loss on the Manchester City feeders. The net result, after bringing the Sheffield figures up to the same basis as Manchester's, increased Mr. Yerbury's figure of 0·668d. to 0·81d. Mr. Yerbury, in the columns of the *Electrical Review*, thought the method of comparison was not quite fair. We should, he said, have brought Manchester down to the Sheffield basis. What does it matter whether we bring Sheffield up to the level of Manchester or *vice versâ*, so long as we compare like with like? What is Manchester's figure for that portion of the system—viz., the central area of the city, which is strictly comparable with Sheffield? I refer now to the low-tension portion supplied from our Bloom Street City works. After a good deal of trouble we got out the figure for Bloom Street, and it was 0·88d. per unit generated, so there you have the difference—0·81d. for Sheffield and 0·88d. for Manchester. There is to be said, however, that Sheffield has an output of 13½ millions, and a load factor of 38 per cent.; the Bloom Street portion of the Manchester output is only 8 million units, and a load factor of only 28 per cent. I am content, under the differing load conditions, to give Mr. Yerbury the benefit of the difference in his favour—viz., 0·07d. per unit. Mr. Pearce.

I read this paper through two or three times, and I am bound to say that I was very surprised not to find any reference to Glasgow. I am afraid that if Glasgow had been introduced, it would have shown that "the costs of separate traction stations are not invariably lower than the prices charged by combined undertakings." It must be remembered that the Glasgow undertaking is the only one which can be fairly compared with Manchester. The systems are identical, and the outputs are pretty much the same. After going into the comparison very carefully, the net result went to show that Glasgow's figure is 1·14d. per unit as against the Manchester figure of 1·04d., since reduced to 1d. I venture to assert that the Manchester flat rate of 1d. per unit compares exceedingly well with that of Glasgow, or any other similar undertaking. There are certainly one or two other questionable points in Mr. Yerbury's paper. First of all, I would like to say that his assumption that traction business always compares very favourably with industrial power business, may be disposed of in a few words, by contrasting Manchester's traction load factor of 33 per cent. with that load factor obtained at our Stuart Street station, viz., 50 per cent. What does the latter include? Traction supply, lighting, and industrial power supply. I estimate the load factor of the industrial power supply alone as being between 60 and 70 per cent. in our case. Surely a sound justification for charging rates below 1d. per unit to large power users. The next point—and it is a very important one—is the question of peak loads. In reading the paper one would infer that

Mr. Pearce. Mr. Yerbury's opinion is that the peak load, as we understand it in central stations, does not exist in a purely tramway station. I have looked at his recording ammeter sheets, and they are really wonderful curves. It is a very fine traction load. As far as I can see, the mean variation from minimum to maximum is only about 1,000 amperes throughout the day. That seems to me a very constant and steady load, but I should not think it is typical of traction loads throughout the country. What do we find at Bloom Street, Manchester? The morning and evening peaks are very accentuated. There is a difference there of 3,000 and 3,500 amperes between the average minimum and maximum. Mr. McElroy, in his report on the question of halfpenny fares, speaks of the effect of introducing these in Manchester as being most serious on account of our high peaks. If there are high peaks on any traction system, I submit that the whole of Mr. Yerbury's argument on this question of apportioning some of the charges for coal, repairs, wages, etc., to standing costs falls to the ground. I want to make it clear when I speak about fixed charges that I include standing charges plus capital charges. Standing charges are the portion of the works operating costs which are incurred independently of the station output, but dependent on the station maximum demand. Whatever may be true at Sheffield, certainly at Manchester there are accentuated peaks, and therefore I cannot agree with Mr. Yerbury that no portion of the coal, oil, wages, etc., items should be debited to standing charges. I admit that the allocation of these items between running and standing charges is a matter for argument, but I think I have stated before in this room how we arrive at ours, and I do not propose therefore to repeat what I have previously said. The apportionment of the coal, which is the principal item, has been confirmed by no less an authority than Sir Alexander Kennedy. If I have made out a case for peak loads, then certainly some proportion of the works costs must go to standing charges, but this point, it seems to me, Mr. Yerbury entirely ignores throughout his paper.

Another point to which Mr. Yerbury refers I would like to speak upon (but this is not altogether the occasion) is the question of the equity of catering for large power supplies at prices now generally ruling. I touched upon it last summer in connection with the Presidential Address I gave in Manchester to the Municipal Electrical Association, and with your permission I should like to read a paragraph from that, which is as follows:—

> "I believe that the majority of power tariffs framed are unremunerative, although in certain cases they may have involved some remission in the fixed charges to large power users. Take the case of a system in which plant is now being put down to deal chiefly with power supplies, the installation of this more modern plant and utilising larger units will on present-day prices only cost one-half to one-third of the price per kilowatt of the plant forming the existing installation erected, say, seven

Mr. Pearce.

> years ago. I think in this hypothetical case it would most certainly be equitable to remit a proportion of the fixed charges on capital in the case of those consumers whilst debiting them with their full share of the remaining standing costs."

This point bears on the incidence of capital charges in relation to the cost of traction supplies. The new plant is probably put down in the generating station in connection with the new and large industrial power loads. In the case of those combined undertakings, where the capital charges are pooled and the tramways department pay a share in the proportion to the total that their maximum demand bears to the total maximum demand of the undertaking, it is clear that they are getting a benefit from the lower priced extension plant installed for purposes other than traction to which they are not strictly entitled. It appears, therefore, that Mr. Yerbury's suggestion No. 1 on page 598 is not altogether in the interests of tramway departments. The Manchester system of charging, as drawn up by Mr. Wordingham and adopted, was based on a compound charge, made up of fixed and running charges, viz.:—

1. A proportion of total running charges exactly proportional to consumption when latter was divided between traction units and other units.
2. A proportion of total fixed charges exactly proportional to maximum demand on generating stations when divided between traction demand and other demands.

It was further indicated that the standing charges, consisting of the cost of being ready to supply, would include: (*a*) Coal burned to make up radiation losses from boilers, pipes, etc.; (*b*) oil, water, etc.—part of; (*c*) wages—part of; (*d*) some of repairs; (*e*) interest, depreciation, sinking fund, etc.

Also that running charges consist of costs over and above costs of being ready to supply, and therefore include: (*a*) Remainder of coal bill; (*b*) remainder of oil, water, etc., bill; (*c*) remainder of wages; (*d*) remainder of repairs. In the agreement between the two committees the annual fixed charge on capital was in respect of monies borrowed by the electricity committee for the provision of generating stations, transforming stations, high-pressure mains, and low-pressure traction mains up to the trolley wires. To the actual running costs per unit was added a profit of 3 per cent. This arrangement has recently been terminated, and for the next three years an all-round rate of 1d. per unit has been agreed upon by both electricity and tramways committees. On another point I must say that I think Mr. Yerbury is altogether too sanguine in estimating the annual percentage necessary to cover depreciation and obsolescence. He takes the figure of 1·75—that figure gives an equated life of thirty-four years. I think that is altogether too long. The lives adopted by the Municipal Elec-

Mr. Pearce. trical Association, which agree very closely with the findings of many other experts, work out an equated figure of twenty-two years.

There is a point on page 598 I would like to mention. Mr. Yerbury in the suggested allocation of expenditure puts all repairs to running charges. Here he is against the general weight of opinion, which favours some portion being placed to standing charges, as all repairs are not consequent on the actual energy produced. For example, the whole of the costs of repairs of cables should not go down to the running costs. Surely the repairs to cables are more governed by outside factors such as chemical action, sinking of the soil, and so on, than by the actual current passed through them. With regard to meters, I believe in giving a tramway department their own meters, and so enable them to obtain every possible check they can. In conclusion, the members will agree that Mr. Yerbury may make out an excellent case for the uniformity of method of charging to be adopted, but it will not be by any generally proved inequities in present-day conditions of charging.

Mr. Salter. Mr. J. R. SALTER: I take for the text of my remarks the statement on page 596 that a bulk supply to tramways effects a general reduction in the generating costs, and the point I wish to make is that in fixing the charges for a tramway supply, the supply authority does not take this advantage to their undertaking sufficiently into consideration. There are many lighting undertakings in this country whose profit, and indeed, in some cases, whose existence depends upon the tramway supply, but I know of no tramways whose existence depends upon the electric lighting supply undertaking. The first criticism on the paper which I have to make is in regard to the comparison between the charges for a tramway supply and for a power or lighting supply. In all cases of tramway supplies the supply is given at the switchboard, whilst a power or lighting supply is given at the consumers' terminals. The electricity undertaking, therefore, bears the whole of the transmission losses when giving a power supply, whilst it charges the tramway undertaking with the transmission losses when giving a tramway supply. In any comparison of the charges, therefore, there should be added to the tramway charges a percentage equal to the losses on the power and lighting network. I would specially like Mr. Pearce to kindly consider this, as he has in his remarks on the comparison between a direct-current supply and an alternating-current supply. We all know, and the paper says the same thing, that electricity undertakings frequently supply electricity for power purposes *under cost* because of the incidental or extraneous advantages which that supply gives; and there appears to be no justification for ignoring the claims of a tramway supply to similar treatment on the same grounds. Indeed, half the stations in this country could not exist without the tramway supply, and yet they omit all those extraneous advantages when fixing the charges for tramways. They then come back to those scientific principles. They tell you about the load factor, and give us a discussion on the amount to be charged as "fixed charges" to the tramways in

Mr. Salter.

regard to such items as coal, wages, etc. I think too much is made of the load factor, and too little consideration given to the quantity supplied. I would rather have a station with an output of 1,000,000 units and a 25 per cent. load factor than a station with an output of 1,000 units and 100 per cent. load factor. The reason is that as the quantity of the output increases (without any regard to the load factor) so do many of the "fixed charges" become "running costs"; that is to say, with a small output many of the "running costs," such as wages and a proportion of the coal, oil, etc., become fixed charges. It is largely for that reason that the tramway supply should be given very much more consideration than it is. I want to call attention, to illustrate my point, to what might be thought a quite insignificant station. That is the Heywood Corporation station, with which I happen to have some association. When I was first called in to advise the Heywood Corporation four years ago, I found they had a station with an output of 68,000 units per annum, and the generating costs were 4·19d. per unit. They then commenced to supply the tramways, with the result that the output increased to approximately 700,000 units, and the generating costs were reduced to 1·23d. The effect of this has been that this station, which was previously unable to take on any power supply at all, has now been enabled, owing entirely to the tramway supply, to supply power consumers at ¾d. per unit. Yet, when fixing the charge for a tramway supply, you insist upon dividing the fixed costs proportionately to the maximum demand. You forget all the advantages that the tramway load has given you, and come back to your "scientific" principles.

Another point about a tramway supply is that whilst perhaps the diversity factor does not entitle this to a consideration, it must not be overlooked that, generally speaking, a tramway requires its maximum supply usually when there is no power supply—that is, on Sundays and Bank Holidays—and the tramways are in a position to use the lighting plant and staff which would otherwise be idle; and for using this idle plant, the lighting authority increases the charge to the tramways because the maximum demand has been increased. I have a case in point: On one of my tramway undertakings I obtain the supply from the local authority, and they charge us: (*a*) Interest and sinking fund on the capital cost; (*b*) a 4 per cent. remuneration on the capital; (*c*) the actual works costs. For the works costs we pay 1·11d. per unit for a minimum supply of 800,000 units, it being assumed that the wages and management costs are then covered, and are "fixed charges" up to that point; and after that we pay 0·37d. for coal, water, oil, and repairs. The total price in this case works out a little over 2d. per unit, the capital charges being fixed by the maximum demand. The point I want to emphasise is this, and when tramway managers begin to realise it, the electricity undertaking will, I fear, suffer. These charges are so high that they limit the number of cars we can put on the line. If I were to increase the number of cars for Bank Holiday, or special traffic, it would immediately increase the maximum demand. The

Mr. Salter. Corporation would then want to increase their capital charges on the proportionate amount of plant, for running five or six more cars on a Bank Holiday. I should probably have to pay hundreds of pounds a year for it, although the plant is available and doing nothing. When tramway managers come to look into it, they will find that the same thing operates even in large cities like Manchester, but to a less degree; they will probably find that if they leave out their extra traffic on Bank Holidays, they will also get such a reduction in the price per unit, owing to a reduction in the maximum demand under this scientific basis, as to justify their not catering for holiday traffic.

The table on page 593 is not quite right with regard to the Heywood Corporation, as that Corporation owns its own tramways and supplies itself. The tables, I may say, are hardly comparable. In some instances the cables are supplied by the electricity undertaking, and in others by the tramways department. In the Heywood case the charges are not by any means comparable, because the generating plant belongs to the tramways department, although it is housed in the electricity works.

Mr. Atchison. Mr. C. C. Atchison: Mr. Salter, in his remarks, has been giving assistance to Mr. Yerbury, for, if anything, he has materially weakened the case against the electricity supply undertakings. The former spoke about the load factor, and he says that the tramways are giving the benefit to the electricity department. As far as I can see, an electricity department for economical working wants to have either a very good load factor, or an abominably bad one, and the fairly good one only which is generally given by the ordinary traction load can hardly be considered of material, if any, benefit; in fact, in some cases it does more harm than good. The Heywood tramways, I understand, could very well have done without the lighting undertaking, yet, in Mr. Salter's concluding remarks, he stated that they had utilised the electricity undertaking's premises and buildings for housing the tramway plant which, at the same time, was attended to by the electricity department staff. I think he must either have made a mistake, or else he has given his case away. Mr. Pearce has ably dealt with some of the points of the paper, and although I want to thank Mr. Yerbury for coming here this evening, I cannot fail to say something against his point of view, as, in a small way, I am supplying electricity from a combined station myself.

On page 586 Mr. Yerbury says that the lighting load lasts on an average 3 hours a day, but he does not say anything about the power load, and, in fact, does not appear, in this case, to give the undertaking the benefit of the possibility even of one. On the same page he says in connection with capital charges, that these are inflicted only on certain consumers, notably tramway undertakings, and, looking through the paper, he appears to consider that these are having an exceptionally bad time when supplied from combined stations. Mr. Pearce has dealt with the question of the peak loads on a large undertaking, and his remarks were quite in accordance with my own experience in a

Mr. Atchison.

smaller way. Also those who are supplying tramways in hilly districts have to deal with considerable fluctuations in the load, and, in our own case, there is also a very distinct peak. The necessity of keeping boilers under steam, and a standby staff for this purpose, I find is absolutely correct. On page 594 Mr. Yerbury says that the tramway does not benefit because the valuation asset, or the then market value of the undertaking, is often ignored. I assume Mr. Yerbury would not suggest that a tramways department is to take its supply from the electricity department for a few years only. If therefore this arrangement were to continue for a reasonable number of years, the tramways department would be able to eventually benefit equally with the electricity department, when there is anything to be gained, due to the capital charges on certain portions of the plant having been completed, as, when you have paid off a loan, it is hoped that there will be some plant in use upon which no interest and sinking fund charges will be necessary. I think it is rather a sweeping statement Mr. Yerbury makes when he says that the tramway effects a general reduction in generating costs; as a matter of fact, I do not think it always does so, at all events in smaller stations, though I am pleased to note Heywood's success in this direction. I quite admit it might be well for the main cables and feeders to be calculated by the tramways department, who in that case ought to bear the initial cost and the annual maintenance and capital charges upon them, because if the electricity department have anything to do with the arrangement and size of the cables, it is always open for the tramways to turn round and say they are incurring losses due to small sections, or are paying charges on too large a capital expenditure; but I consider all street work in connection with cables should be in the hands of the electricity department, so as to have only one department carrying out street work. In regard to meters, Mr. Yerbury seems to suggest again that the electricity department is untrustworthy, and requires to be constantly checked, which I think is rather unfair. As regards standby plant, I would like to point out that in a combined station the 25 per cent. of spare plant stated as necessary for the tramways is utilisable for lighting, and the tramways department is saved capital expenditure. This is a large item to a small electricity works undertaking with a large traction load, and where the traction load is small the tramways benefit by the lower capital expenditure per kilowatt of the larger general supply plant. He seems to ignore the fact that the whole question resolves itself into what is to the benefit of the town as a whole, and not merely to one single department. On page 599 Mr. Yerbury expresses a wish to limit the profits to be made by the electricity department to between 3 per cent. to 5 per cent., and that only on running costs. This I consider absolutely unfair. First of all, fixing the profit on running costs will in many cases practically halve these suggested percentages; and further, it appears that the tramways department is to be at liberty to make whatever profits it likes and can obtain in the course of its working, and as part of its costs are for power, any reduction in the price of

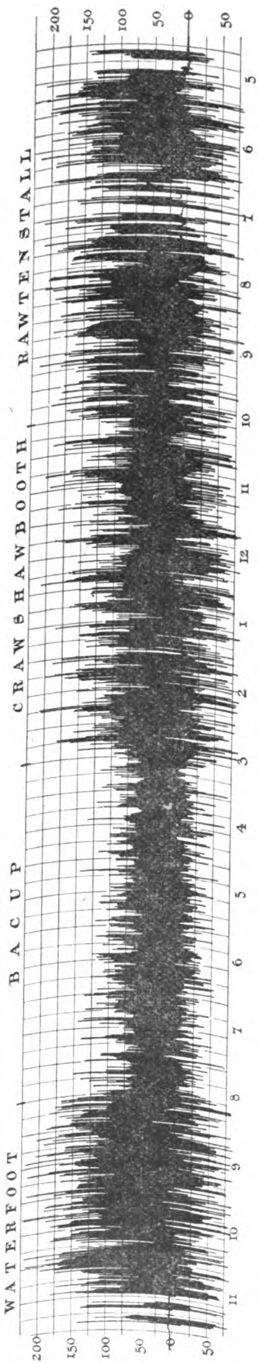

Fig A.

Mr. Atchison.

the power supply tends to increase the profits; in other words, the tramways department would limit the electricity supply profits to increase its own.

Mr. Stewart.

Mr. C. L. E. Stewart: One point that struck me is with regard to the load factor. If you have a big tramway supply, you get some idea of the load factor worked out in the ordinary way, but when you come to a small tramways it may be that the load factor is 20 per cent., and if you compare that with 20 per cent. from a private consumer, there is a very great difference in the two, because the private consumer would knock off his 20 per cent. in, say, 10 hours. He would take it on at fairly full load for 10 hours, whereas you get your load on the engine running anywhere between nothing (and in our case less than nothing) to a fairly big overload. At Rawtenstall it is rather interesting to see the effect on the engine when you are getting 50 k.w. to 100 k.w. coming in and nothing going out; a load factor of about 15 per cent. is obtained, which really means a very poor load factor on the plant running at any particular time, and in this way the supply to small tramways is at a great disadvantage compared with a large undertaking. I agree with what Mr. Salter says about tramway undertakings in regard to the expenses of the electricity undertaking, and it applies very much indeed to their initial days, because at that period of the electricity undertaking they have no custom whatsoever. If they can make sure of a certain fixed income, it enables them to make a bid for business which they otherwise could not do at all. I think that a definite basis should be arrived at for charging for tramway current, and that all towns should work to this basis whatever it may be. I would suggest that the following points be considered. On referring to the curves shown on pages 585 and 587 it will be noticed that the curves are made up of two parts: the solid portion

and the fringe. Now the fringe is the least desirable portion of the curve to the electricity works, and in a small tramway system the electricity works only gets the fringe. As the number of cars increases, the fringe is raised bodily above zero and leaves a portion representing dead steady load beneath it. (In the curves shown there is a steady load of approximately 1,500 k.w. for 18 hours in A; 1,500 k.w. for 5 hours, and 2,000 k.w. for 11½ hours in B; 1,200 k.w. for 4 hours, and 2,500 k.w. for 12½ hours in C. This lower portion is about as desirable a load as an electricity works could desire, as it is on for a large number of hours every day in the week, and should be charged for at a very low rate, and the portion representing the fringe should be charged for at a relatively higher rate. I do not mean that two charges should be made, but I think the relative values of the two portions could be worked out and then compounded into a flat rate. In our case, with a maximum load of about 400 k.w. we get a variation of load of 450 k.w., which represents the fringe starting rather below the zero-line. We have no recording ammeter for showing the total current, but Fig. A shows a recorder sheet taken on each of our four feeders for a few hours during the day. The instrument has been set with the zero at the 75-ampere mark so that the reverse current may be seen. Mr. Stewart.

There is no question about it, a somewhat strained feeling does exist between tramways committees and, to some extent, tramways managers, against electricity undertakings, and it would seem to me that tramways managers are sometimes short of particulars which would be of assistance to them. In some undertakings the load will go up in a most extraordinary manner, and the tramways manager will tell the electrical engineer that his meters have gone wrong. I found that ours went up a little while ago, perhaps 30 per cent., and having the particulars at hand we could locate where the current was going to and soon got back to the normal figure. I think if the tramway people would satisfy themselves where the current was going to it would help them forward. The impression I get from managers is simply that the electrical engineers try to get as much current sold to them as it is possible, whether it is used or wasted.

Mr. Miles Walker: I think that when we are discussing equitable charges for electricity something should be said about power factor. A tramway department having modern plant and drawing current at unity power factor ought to receive more favourable terms than a tramway department drawing current at 0·8 power factor. The amount of the concession would, of course, vary under different circumstances, but, roughly, it may be arrived at in the following way: A power factor of 0·8 calls for a 25 per cent. increase in the total kilo-volt-amperes, which means that the capacity of the generating plant and cables is increased by this percentage. The total capital will be increased by about 8½ per cent.; in some cases it will be by a greater percentage. Now the capital costs are more than half the total costs, so that the total costs of generation including capital charges will thus be increased by about 4½ per cent. Then we must allow something Mr. Walker.

Mr. Walker. for loss of efficiency. The loss of efficiency in generation and distribution due to a lagging power factor of 0·8 will be about $1\frac{1}{2}$ per cent. on an average. This added to the $4\frac{1}{2}$ per cent. gives us 6 per cent. as a fair concession to make to users at unity power factor. In cases where the user has synchronous machinery, and can run on a leading power factor, a further concession should be made to him in those cases where the leading power factor is of commercial advantage to the supply station.

I think that at the Conference which is about to take place on the equitable charges to tramway undertakings something ought to be decided on the question of what is a fair concession to make to a tramway undertaking for improving the power factor of the whole station.

Mr. Whysall. Mr. F. H. WHYSALL : The general conclusions I have come to on the discussion are that everybody looks at the matter in the first place from his own standpoint, and the whole business is tied up for want of a common basis of comparison. It seems to be a very difficult matter indeed to get things on all fours with regard to separate traction stations. Conditions with regard to arriving at costs per unit are very largely in the hands of the people managing those stations. With reference to combined undertakings where current is sold to another department, or to a company, the matter of deciding what should be the cost per unit is very different. The people who buy the current have to be satisfied that the charge from their point of view is just, and it seems a very different thing doing that to deciding, say, what you will put down as a departmental figure. I do not think we shall get anything like comparisons until everybody is interested in this subject, and we set about getting these figures on a more common basis of comparison. The only thing that the undertakings can do now is to satisfy the department supplied—when a separate department—and in the case of a separate traction undertaking where it is only a question of arriving at the amount to be put down in the accounts, they can only satisfy the people responsible for the undertaking. It is not a matter of such vital importance.

Mr. Watson. Mr. S. J. WATSON : I am sorry that the points put forward by the author with a view of inviting criticism have not received the attention they deserve during the discussion, and it is to these points that I propose, as far as possible, to limit my remarks. Mr. Yerbury deserves the thanks of both tramway and electricity works managers, because the price charged by electrical departments for tramway supplies has at times given rise to a great deal of friction between them. The object of the paper, I take it, is to obtain the views of those acquainted with the subject, with the idea of formulating some definite method of ascertaining the total costs of the supply when it is given to a tramway department from a combined station. I do not agree with Mr. Yerbury's proposals in regard to taking "the running costs" as the whole of the coal, water and stores, wages and repairs items. While this may be correct in the case of a station supplying only one kind of load having

Mr. Watson.

a certain load factor, it is incorrect when applied to a combined station supplying light, power, and tramways, where each class of load has a very different load factor. The running costs consist of the bulk of the coal, oil, and water costs, and a very small proportion of the repairs account. All the wages, the bulk of the repairs, and the remaining portions of the coal, with oil and water costs, are standing charges, because these costs have to be incurred in keeping steam up and the plant in readiness to run on load irrespective of the actual output. This alteration would appreciably change some of the costs given in the paper; for instance, if the works costs of a given combined station are taken at 0·50d. on a combined load factor of 25 per cent. consisting of tramway supply having a load factor of 30 per cent., and the light and power supply having a load factor of only 15 per cent., it is evident that the 0·50d. per unit is more than should be debited to the tramways, whereas, should the tramway load factor be but 20 per cent., and the light and power load factor 30 per cent., the price would be too low. Incidentally it may be mentioned that this is one of the reasons why power consumers are entitled to be charged very much less than the lighting or tramways, inasmuch as the load factor is usually between 35 and 40 per cent. Mr. Yerbury's remarks concerning the steadiness of a tramway load may be correct for Sheffield or for some other very large tramway systems, but he is very wide of the mark where smaller systems are concerned, especially in hilly districts. In my own town the tramway load is constantly varying from about 50 k.w. to 600 k.w., and in consequence of this variation the mean load on the running plant is only about one-third the full-load capacity, which is hardly the ideal conditions for obtaining low running costs. In comparison with this the power load is practically constant during factory hours, and there is no likelihood of any variation; plant can consequently be run under the most economical conditions, and the running costs must be considerably lower than for the tramway supply. He further mentions that tramway peak loads do not come on at the same time as the lighting and power peak loads; here again I disagree with him. My own experience is that there is nothing to safeguard this occurrence, and, as a matter of fact, during the last month or two, owing to heavy falls of snow, the maximum tramway load has actually occurred at the time of the lighting and power peak load. It is also a common occurrence to have football cup-ties or other special events on weekdays, and when these occur the traffic may reach its maximum quite a little time after sunset, by which time the light and power peak has been practically reached.

I agree with Mr. Yerbury's remarks concerning feeders. A tramway department, owing to the requirements and demands of the traffic, practically settle the loss in the feeder cables, and they should therefore provide and pay for the feeders as part of their own equipment. With a large tramway system it may also be better for the tramways to maintain the feeders, but in small systems it is very much more convenient and less costly for the mains staff of the electricity department to carry

Mr. Watson. out the work at the cost of the tramway department, as they possess instruments, tools, and the necessary organisation for the purpose. In connection with the allocation to the tramway supply of a portion of the management, rates and taxes, and insurance charges, it may be of interest to state how I have dealt with this matter in Bury. In the first place, I take the total charges under these headings and deduct what I consider is the cost incurred in connection with the preparation and collection of consumers' accounts. Then I assume that the amount remaining is attributable partly to expenditure outside the works, which has nothing to do with the tramway, and partly to the inside equipment, which does concern the tramways, and I therefore divide it up into two parts on the basis of capital expenditure on mains and meters, etc., and on generating station equipment. The amount obtained in this way for the generating station is then divided between the plant used for tramways and for other purposes on the percentage of maximum load of each to the total plant installed.

The principal difficulty in bringing the tramway power station costs in line with combined station charges, in my opinion, lies in the amount that is to be included in the charges to cover the capital expenditure and risks incidental thereto. I have made a few comparisons between the costs of tramway stations and the charges by combined stations in the same district, and I assume that in order to be in a perfectly sound financial condition, it is necessary for either a tramway department or an electricity department to have a gross profit of from 8 to 10 per cent. on capital expenditure after paying all working expenses. This appears to be in accordance with the practice of the most successful undertakings of both kinds, and must, I think, be admitted as a sound commercial view of the case. I find that the cost of power generated and supplied to the Blackpool and Fleetwood Tramway Company was, last year, 0·97d. per unit, and that the charge made to the Blackpool Corporation Tramways by the electricity department was 1·79d. The former cost is works costs only, whereas the Corporation charge is works costs, proportion of management, capital, and other charges on plant, and capital and maintenance charges on mains. I assume also that the company's generating station, sub-station, and mains cost £30,000, and that the Corporation expenditure on plant and mains amounts to £40,000; also, that the rents, rates and taxes, and proportion of management charges amount to 0·10d. per unit in both cases. Making the necessary adjustment, on these lines the cost of the company's supply comes to 0·95d. running costs, plus 0·10d. for rates, etc., plus 0·74d. for capital, etc., a total of 1·79d.; and the Corporation costs to 0·92d. running costs, plus 0·10d. rates, etc., plus 0·71d. for capital, etc., a total of 1·73d. The load factor of both stations is about 13·5 per cent. It is evident that both these costs are practically alike, and that the Corporation's charge of 1·79d. is not excessive, although, doubtless, some tramway managers would consider it so.

In the case of Hull, which also possesses two stations, the works costs of the tramway station is 0·65d. per unit, and the load factor

Mr. Watson.

probably 25 to 30 per cent. The running costs of the lighting and power station is 0·73d. on a load factor of under 13 per cent. If the costs are reduced to the same load factor and the same percentage be added for capital and other charges, the costs in both cases would be about the same, *i.e.*, about 1·20d. per unit. Mr. Yerbury has amended the figures for Birkenhead, where the works cost are now given as 0·79d. per unit, again adding on management and rates, also capital charges; the total cost comes to about 1·20d. per unit. I particularly mention these three cases because they may, I think, be taken as fairly typical examples of the smaller tramway undertakings, and a reference to the charges given in the tables will show that there are quite a number of combined undertakings charging from 1.10d. to 1.30d. per unit for the tramway supply, excluding capital and maintenance charges on mains; it must therefore be conceded that the extraordinary overcharges mentioned by Mr. Yerbury do not exist in practice to any considerable extent. He may, of course, contend that electricity departments are not entitled to charge as much as 8 to 10 per cent. to cover the costs, etc., but he must admit that in the majority of cases the tramway authorities have considered it necessary to arrange their fares, etc., so that this amount is left over after paying all costs, and this percentage is taken on the cost of the generating station as well as on the tramway equipment proper. Such being the case, I cannot see why tramway departments should expect electricity departments to charge the bare manufacturing costs in order that the tramways may sell to the public at a higher cost and show in their balance-sheets additional profits, for which they are in no way responsible. I totally disagree with the author's contention that the profit made by the electricity department should be only 3 to 5 per cent. on the working expenses, and to enable you to see what the difference is between a profit based on Mr. Yerbury's proposal and on the results actually worked for by tramway undertakings, I would state that the net profit, after paying all capital charges in addition to working expenses, of five tramway undertakings possessing their own generating stations, whose total capital expenditure is £6,841,094, amounts to £416,959, equal to 6½ per cent. on the capital; and the working expenses of the five amount to £985,000. If 3 per cent. is taken on the working expenses, the profit allowed, according to Mr. Yerbury's proposal, would be £29,550, whereas I contend that the manufacturer is entitled to a sum approximating to the £416,959 of net profit. From these figures it will be seen that the difference dividing the two interests is no small one. There is one other small point which I should like Mr. Yerbury to clear up. With combined stations the sales are invariably metered on to feeders. I would ask whether in the tramway stations mentioned the units are metered in the same way, or do the figures given refer to units supplied by the generators, and therefore include works lighting, feeder and other booster, motor auxiliaries, etc.? The difference between the two may be as much as 15 or 20 per cent

DISCUSSION AT GLASGOW, FEBRUARY 8, 1910.

Professor Baily.

Professor F. G. BAILY: With the general contention of the paper I have much sympathy. In many cases where there have been contracts or propositions between a tramway company or department and a supplier of power the terms of sale have appeared to me to be unduly favourable to the sellers. Still I admit that a tramway company is not quite on a par with other consumers of power, and it is concerning this difference that I have some criticism to make on a part of Mr. Yerbury's paper. There has been of late a practice of criticising electric station accounts on the ground that the charge for power is not based on sound business principles, that it is an unremunerative price, adopted merely for the sake of getting business, and it is roundly stated that the loss is recouped from the lighting consumers. Much has been written about scientific tariffs, and I cannot but feel that we are suffering from too much rather superficial economic science, and that too little consideration is being given to the well-tried experience of commerce in other lines of business. A principle which is adopted widely by shrewd men of business cannot be dismissed as fundamentally wrong, though it may not be universally applicable. Mr. Yerbury adopts these somewhat elementary economic statements, and follows the opinion that the price of a single article is the cost of production of the whole output divided by the output, and that any divergence from this price must be commercially unsound.

We have heard so much of late about the theory and practice of "dumping" that it should be unnecessary to do more than mention the word to render the whole position clear. But it appears not to be always appreciated that the process is not confined to dealings between countries, and further that the practice is not essentially an evil one. It may be almost completely stated in a few words. It is agreed that, broadly speaking, the cost of production of manufactured articles decreases as the output increases. Therefore by increasing his business a manufacturer reduces the cost per article and obtains a more and more favourable position. But the astute manufacturer further sees that the cost of the additional articles is still less, and if he can find new customers at this smaller rate without disturbing his previous business a much larger field is opened out. In the ordinary market this is scarcely possible, for old customers would certainly demur at being asked to pay a higher price than new ones, and this difficulty is avoided by tapping another country. In the sale of electricity there is the additional obstacle that preferential treatment of similar consumers is illegal. But if a new class of consumers can be found at the price of additional manufacture the old lighting consumers are in no way injured. The extension of the business is not possible if the new customers are left alone, and therefore the old customers have, strictly speaking, no claim on the reduction of price brought about by a new class of business. All of

Professor Baily.

this statement is, of course, very obvious and well known to the manufacturers, but it has been ignored by their critics. So far indeed from having a grievance, the lighting consumers have had their charges steadily reduced almost universally, and it would be difficult to substantiate the statement that they are entitled to further reductions on account of the increase of the pure lighting output. But a further criticism of the price for power states that if power consumers increase unduly bankruptcy will ensue. This seems to me precisely the position of affairs when an enormous consumer like a tramway comes on the scene, with a demand that practically means reorganisation of the plant and staff. In such a case it is not unfair nor unwise to put the prices in the melting-pot and to recast them with a proper proportion of all charges to each. How far this apportionment has been fair requires a most detailed examination of each case, and cannot be solved by a mere tabulation of charges in various towns; but I am inclined to think that this second criticism of the low power rate contains much of the answer to the grievances put forward in the paper. It is quite probable that the proper charge for the tramway would come out higher than that previously and properly paid by the power consumers; but it seems manifestly unfair to the latter to put up their charges because of the acceptance of the tramway load, while it is impossible to accept the tramway at the old power rates. Granting Mr. Yerbury's method of costing, his statements concerning that basis seem very moderate. In his summary of charges more has been debited against the tramway department than need be. It is, for example, obvious that the proportion of the time of the management taken up by numerous small lighting consumers is far greater than their kilowatt capacity of plant would allocate to them. Likewise in the items under "running charges" the severe requirements of the lighting consumer are costly, and the due proportion of the expenses is not that of the respective consumptions. Hence I consider his general claims may be even increased, but I doubt if the results of the accounting would appear so favourable as he anticipates, though some reduction does seem due.

Mr. Robertson.

Mr. J. A. Robertson: I think Mr. Yerbury has fallen into the mistake of generalising from his special experience in Sheffield. This is a question where each case should be considered according to local conditions. I am interested as representing the suppliers of electricity in a much smaller town than Sheffield, and I am afraid the paper will be used against us when the question of rates comes to be discussed. The curves shown by Mr. Yerbury are very different from the curves we get at Greenock, and although we have under agreement to provide plant for a maximum demand of 600 k.w., our actual sale of energy last year amounted to only 680,000 units, or a plant load factor of 12 per cent. The actual maximum demand during this year amounted to 450 k.w., giving a load factor of 16·3 per cent., but our load factor for the whole output of the works is 18·5 per cent., and some of our power users have load factors from 30 to 35 per cent. Again, the

Mr. Robertson. diversity factor from power consumers is fairly high, and although Mr. Yerbury speaks of a *tramway diversity factor* it is not a diversity factor at all in the true sense—viz., the ratio between the sum of the demands made by consumers and the actual demand on the station. I do not agree with Mr. Yerbury that the sum he is setting aside for depreciation and sinking fund is sufficient, and his figure compares badly with the amount set aside in Glasgow. Some undertakings were started as combined stations eight or ten years ago, plant being provided specially for tramway supply. In the interval the lighting and power business has grown, and it is found that owing to the lower prices ruling for plant, additions can be made to take on new power users at a much lower charge per kilowatt than the cost of the original plant; but immediately one proposes to do this the tramway department asks for reduced prices also. To some extent they are justified, but it must not be overlooked that plant must be set aside specially for tramway generation, and that while the power load is usually a growing load with increased diversity factor, the tramway output is stationary after the first year or two. Separate stations in any but the largest towns are out of the question entirely, and any comparison made on this basis will show that energy cannot possibly be sold from a separate station as cheaply as from a combined station. The accuracy of Mr. Yerbury's meters as stated on page 597 is remarkable, and he will find very few station engineers with similar experience.

Mr. Neilson. Mr. R. M. NEILSON : This discussion ought certainly to do a lot of good. As has already been said, the conditions are so different in different places, and the ratio of tramway load to total load varies so much that any rules which would be equitable in one case would not be at all fair in another. I quite realise the difficulty of the problem because quite recently in connection with condensing plant the following somewhat analogous question arose : If you have an option of putting in an expensive condensing plant which will consume little power, and putting in a cheaper condensing plant which will consume more power, and if you have to consider which is best, you require to determine what price to charge against the condenser auxiliaries for the power which they consume. Obviously the more the power required by your condenser auxiliaries, the greater must be the capacity of your main units, and therefore you ought to charge the condensing plant with a portion of the first cost of the main units ; and it is open to question if you should not also charge the condensing plant with a small portion of your running costs as regards salaries, wages, and some other items. The problem is, without doubt, a complicated one. I think Professor Baily in his diagram meant to include not only running costs but first costs, and, if so, his argument was undoubtedly right as far as it went ; but he did not, I think, pursue the subject far enough. If you decide to have a combined station, your decision is only justified if you are going to benefit thereby, that is, if the combination is going to flatten the curve ; otherwise you may as well have two separate stations, and if the combination is going to flatten your curve and your tramways

are owned by the corporation who control the generating station, then the tramways, as well as the generating department, ought to benefit by the flattening of the curve. With regard to the total cost of generating stations given on page 594, it would be very unfair in some cases to make use of such figures. If a tramways department at the present day is to be charged depreciation and interest on first costs as high as those given on page 594, it may be very unfairly charged. The station costs referred to vary from £35 to £61 per kilowatt. I have no doubt that stations have cost these amounts—and I think some have cost more than the higher figure stated—but modern prices are, or ought to be, much lower. If a station is extended to provide current for tramways, the extension will not, or at least should not, cost anything like the figures stated. Boilers cost somewhere between £3 and £4 per kilowatt, turbo-alternators £3 or £4 per kilowatt, and condensing plant from £1 to £2 per kilowatt. The building and the extras should not bring up the cost to anything like £35 per kilowatt. Mr. Neilson

Mr. W. W. LACKIE: Mr. Yerbury has brought a very important subject before us, and one which is engaging the attention of municipal engineers and tramway managers throughout the country. I am sorry that a more definite conclusion has not been come to in the paper. Mr. Yerbury agrees that the cost of electrical energy is properly divided into two parts: viz., standing charges (representing interest, sinking fund, depreciation, etc.), and running costs. I do not agree with his allocation of the fixed charges and the allocation of the running costs. I am somewhat astonished to find on page 598 in his summary he divides the cost of electrical energy up into no less than five heads. In connection with the price of electrical energy for tramway purposes, it appears to me that the fixed charges should include practically everything except fuel, water, oil, and waste. Interest, sinking fund, and depreciation are undoubtedly fixed charges, but for a tramway supply salaries, wages, and repairs to plant appear also to be a standing charge, irrespective of the number of units sent out. The only thing that varies per unit is the fuel, oil, and water. The author agrees that the maximum demand is the fairest system of charging, and I am surprised that he does not apply this system straight away in order to get an equitable charge for a tramway supply by advocating a charge of £4, £5, and £6 per kilowatt of maximum demand plus ¼d. and ⅛d. per unit. It is true that a tramway load is taken over a period of 16 to 20 hours, but it is found that the consumption is only equivalent to a maximum demand of some 8 hours per day, giving a load factor of some 33 per cent., and there are many commercial power consumers giving a very much better load factor than this. The great difference between a tramway supply and a supply to a commercial concern for power purposes is this, that separate plant has to be allotted to supplying the tramway demand, whereas the supply for an ordinary industrial power load can be used to supply lighting or power load indiscriminately. This means that there is a diversity factor in the machinery required for the ordinary supply, and there is no such factor in a tramway Mr. Lackie.

Mr. Lackie.

load, which is due to the fact that the tramway supply uses an "earthed" return. In Glasgow we do find that there is a peak load in the tramway station, and on page 598 of the paper Mr. Yerbury admits that there are peak loads, and these occur on Christmas Eve, the very time when there is a peak load for the lighting supply. The capital cost of high-tension and low-tension systems cannot be compared if we do not include the whole of the mains on both systems. It is incorrect to say that the running cost for a high-tension supply is more than that for running a low-tension supply. Mr. Yerbury gives the whole case away when he says at the bottom of page 598 that no hard-and-fast rule can be laid down as so much depends upon local circumstances. There is no doubt about it—in Glasgow at least—that a combined station or stations would now be the most satisfactory thing, but at the time when the tramways department decided on electrification, their demand was much in excess of that of the electricity department, and they decided to put down a separate station. I would like to refer to Table II. on page 589. There the rates of charges for lighting and power in Glasgow are given, and it is stated that the works cost for a tramway supply are 0·35d., and the total cost 0·757d. I do not know where these figures were obtained, but I find, on looking at the tramway accounts for the past year, that the works costs were 0·35d. as stated by Mr. Yerbury, but the total costs were 1·227d. This, however, was on the total high-tension units issued from the power house, the actual cost per direct-current unit at the low-tension busbars being 1·41d. The load factor in the electricity station is 18·23 per cent., not 16·83 per cent., and the load factor on the traction station is 39·8 per cent. on the number of units generated, but on the direct-current units it is only 33 per cent. The comparative costs of two stations—Bradford and Sheffield—given on page 588, are thoroughly unsatisfactory. Neither the maximum demand nor the load factor of the high-tension station is given. If in the Sheffield tramway department they get money at 3·13 per cent. they are very fortunate, but if their sinking fund is only 2 per cent., and depreciation and renewals only amount to 1·8 per cent. (a total of 3·9 per cent.), I am pretty certain that the Bradford Corporation are allowing twice this. I consider that a fair charge is: Interest, 3·5 per cent.; sinking fund, 3·3; reserve fund, 1·2; total, 8 per cent. In the low-tension tramway station quoted the total allowed is only 6 per cent. Further, these standing charges should be quoted at a rate per kilowatt per annum, and not at so much per unit.

Mr. MacMillan.

Mr. Campbell MacMillan: I am merely appealing for information in addition to what we have already got to-night. No doubt, after the discussion which this paper has been subjected to, the author will be able to put his replies in a concrete form, which will add value to this very useful paper. The question set out for solution seems to me to be one more of an engineering than of a commercial nature, and the most interesting thing would be a clear explanation of how the combined station fails to yield the proper supply of units at as reasonable a price as the separate station, whether it is merely a matter of accounting or

really a matter of engineering. After all, a problem of equitable charges is not decided by simply deducing selling prices from some method of estimated costs, but such questions of charges are decided by quite other considerations. It would be interesting to have some light thrown on the relative strategic positions of the different people engaged in such arrangements as buyers and sellers. There is no satisfactory method of preventing the last surplus units being sold at almost any price. It is not peculiarly an electric problem, but is a problem in all available markets. It is a question of the sacrifice at which you are going to hold your "bargain sales." The first market may yield reasonable prices, but if you make an article in large quantities it may be good business to supply at absolutely cost price at first to new consumers, for the simple reason that the first market is saturated at the higher price, and then later on you recoup yourself in the extended market. Mr. MacMillan.

Mr. J. P. McMahon: I agree with Mr. Yerbury on the whole, and have listened with interest to the discussion. I presume from the points raised that the speakers are interested principally on the generating side. I take the opposite view, and go over to the side of the buyer. It is most important that tramway companies should be able to obtain their power at a very low cost, more especially with undertakings running through urban and interurban districts, as it might take a considerable time before a return could be secured on their outlay. Mr. Lackie seems to be in favour of combined stations, and Mr. Yerbury has reminded us in two or three places in his paper that the price charged to tramways is considerably more in combined stations than the total cost in separate stations, and rightly he asks, Why is this? I hope we shall get the answer from the generating friends who are here to-night. Some of you no doubt will remember Mr. J. S. Raworth's paper on the "Generation of Electrical Energy for Tramways" before this Institution in London in 1897, wherein he pointed out the principal object of his paper was to show that a suitable and buying price for the supply of energy for tramway purposes under reasonable conditions was 1d. per unit, and that the said supply will reduce the cost of the lighting current when both are generated in the same station by an amount which, though small, is definite. Quoting some figures, he takes a station with a capital outlay of £17,000 producing 1 million units per annum. The total cost works out at 0·671d. per unit. At a selling price of 1d. per unit there is a balance of 0·329d., leaving a profit of £1,370, or 8 per cent. on the £17,000. Some six years later I put down a plant for a separate tramway supply at Northampton. The total cost on the station amounted, roughly, to £17,000 on an output of 878,000 units per annum. The total cost amounted to 0·62d. per unit. If we were selling at 1d. per unit there would be a balance of 0·38d. per unit, giving a profit of £1,205, or 7½ per cent. on the outlay. When figures of this kind can be obtained in small separate undertakings, one is at a loss to understand why large stations like Manchester and Liverpool, for example, cannot Mr. McMahon.

Mr. McMahon. supply their tramways at a much cheaper rate, except it is that there is an unkind legacy of some unknown value included in their combined stations.

Mr. Lackie. Mr. LACKIE: The tramways department station at Pinkston and the lighting station are practically combined. We exchange current frequently.

Mr. Burbidge. Mr. A. H. BURBIDGE: I wish to speak from the point of view of a small undertaking which combines tramways and electric lighting, and therefore find it difficult to criticise the paper. I am of opinion that the tramway cables should be laid and maintained by the electricity department, the size, etc., of cables to be fixed by the tramways department, for the reason that, except with very large undertakings, there are no jointers on the tramways staff, and nobody, as a rule, knows anything about the testing of cables. With regard to meters, my own personal opinion is that at least three meters should be installed to record the tramway consumption. Not long ago I took the trouble to get two separate traction meters tested. The makers returned them, and stated that they were within 2 per cent. on the average load of our traction supply, yet when they were put into circuit there was a difference of 15 per cent. between them. Meters, I believe, are a greater source of difficulty between the tramway manager and electricity department than anything else. The tramway department naturally complains when their current bill for the month is high, and the electricity department can give no reason for it. Standby plant with small undertakings is a very important point. The average load during the week will be easily managed by, say, one engine and dynamo, but on Saturdays and holidays another engine and dynamo has to be run, which latter has to remain as standby plant; this should certainly be paid for by the tramways department. The plant load factor of a small tramway undertaking is somewhere about 25 per cent., but the plant load factor of the power supply is very much higher, and consequently it is quite fair to charge a higher rate for tramway supply, because it must be remembered that the power consumer is supplied from the lighting and power mains, but the tramways supply has to be taken from a separate engine and dynamo, which, as a rule, cannot be used for any other purpose. The question of the amount of profit to be charged on the running cost seems to be more or less a matter for individual corporations to decide, as it really depends upon how much profit they consider one department should make off the other. In many cases a good deal depends upon the state of finances, and I think they are quite justified, so long as they pay their running costs and proportion of capital charges, in increasing or decreasing the amount of profit, depending upon the balance-sheet of the undertaking. In my own undertaking conditions are exactly opposite to what Mr. Yerbury refers to, for this reason, that the tramways have been supplied for the last five years at a figure which I consider barely sufficient to meet the cost of supply. If Mr. Yerbury's method of computing the price to be paid be taken, I find there is

a profit this year of about 2 per cent. on the running charges. With regard to combined stations *versus* separate stations, it is only in the very large towns that separate stations would be considered from the municipal point of view. Mr. Burbidge.

Mr. J. A. BELL: On page 586 Mr. Yerbury states that the "peak load in a tramway station may almost be said to be non-existent as compared with a lighting station"; and again, on page 598, "At all times when a tramway demand is at a maximum the lighting and power is at a minimum, etc." This may represent the conditions in the South, but is not the experience in Aberdeen. For example, for years past between the dates of November 23rd and February 17th the maximum load for the day, as far as lighting and power is concerned, occurs between 4.45 and 5.45 p.m. This repeatedly coincides with the heaviest load of the day for traction, as is not uncommon in most towns, namely, the hour when people return from business. An increased peak on top load due to tramways is therefore the result, and if you add the additional load due to snow, often occurring at this time of the year, we frequently have an exceptional peak load for tramways coinciding with maximum loads for lighting and power. On page 586 Mr. Yerbury rightly points out that the stresses and strains on plant due to enormous fluctuations predicted by our American friends are in practice unfounded. That a normal tramway load is, however, responsible for considerably more wear and tear to plant than a lighting and power supply is certainly my experience. Two 700-I.H.P. Willans engines, each fitted with 9-ton flywheels and identical in every other respect, observed over 7½ years, giving the following results:— Mr. Bell.

	Units Generated.	Cost for Repairs of Wearing Parts of Engine only during Period.	Cost per Unit.
		£	d.
Engine A— Used on lighting and power ...	4,806,630	21	0·00105
Engine B— Used for tramway supply only ...	5,257,789	86	0·00390

In other words, practically four times the amount has had to be spent on repairs for the bearings, etc., of the engine used for traction alone as against similar plant used for lighting and power. This in all probability is more pronounced in hilly towns. *Main Cables and Feeders* (page 596).—Dealing with a moderate-sized town, I consider it most undesirable, both from a financial and working point of view, that feeder cables should be either laid or maintained by the tramway department when supplied by combined stations. Tramway feeders, if properly

Mr. Bell. laid, should require very little maintenance. A combined station is of necessity obliged to keep a permanent staff of experienced mains' men and jointers for lighting and power supply. In the event of tramway feeders requiring attention the necessary skill and labour are available, and the time the men are occupied on such work can be charged against the department concerned. The tramways thus benefit in having expert assistance when required, and only paying for it in case of need. I should hesitate to send an ordinary overhead linesman, however competent, to locate a cable fault, and, of course, the fewer the faults on tramway feeders the more likely to be rusty in cable work is the jointer-cum-linesman. Mr. Yerbury states as one of his reasons for the cables being in charge of the tramway department that "Board of Trade tests have to be taken periodically!" This is quite true, and Board of Trade tests have to be taken twice daily at the switchboard in the generating station. Why, therefore, have tests of cables undertaken by two departments? From a working point of view it is an advantage to have the road operations in connection with cable laying confined to one department, and it prevents multiplication of apparatus and tools. It is, in my opinion, of the greatest advantage, from the tramway efficiency standpoint, to have the whole of the distributing system, namely, cables and overhead construction, in the hands of the supply authority (when the same is a combined station) as is now done in many towns, some of the reasons being that: (1) There is no division of responsibility; (2) all serious faults on overhead construction or on feeders are first observed on the switchboard at the generating station (this is, of course, dealing with a low-tension station); (3) it is usual to have section-box telephone cables laid conjointly with feeder cables, and their natural terminus is at the generating station switchboard.

Mr. Dryer. Mr. W. P. DRYER: We have heard of the difference in the systems in Scotland and England, and it might be interesting to compare them with the method of one of the largest new companies in the United States. I refer to the Tramway Company in Chicago. Up to three years ago that company had three generating stations, but since then they have found it better to buy from the joint lighting station. It is a very large station, supplying about 130,000 k.w. The system they adopt there is that they charge 0·25d. per kilowatt-hour, in addition to a readiness-to-serve charge of £3 per year per kilowatt of maximum demand for any one hour. The figures there work out at lower than any costs given in this paper.

Mr. Richardson. Mr. H. RICHARDSON: In the comparison between a tramway department and a large power consumer it is not always the case that the former, although its hours of demand are longer, has a better load factor, as inferred by Mr. Yerbury. It is not every town that has such a narrow load curve as in Fig. A, and with a hilly town and fewer cars the pen may travel over almost the whole width of the chart. In such cases it is comparatively easy to find large power consumers whose load factors are superior to that of the tramway.

Although apparently the fact has not been realised by Mr. Yerbury, the whole of the cost of the items classed by him as running charges is not proportional to the units generated, but only a part, so that an improvement in the station load factor reduces the running costs generally, and allows current to be sold to other consumers cheaper than would have been possible without the help of the consumers who improve the load factor. In this connection I do not think the author's statement is to be taken as correct, that engineers invariably include more in fixed charges than are appropriate to the actual maximum demands that have to be met, nor does the proportion of coal cost mentioned as allocated in the case of Manchester, *i.e.*, 21·5 per cent., seem unreasonably large. In the case of a 2,000-k.w. turbine running at 75 per cent. full-load, the fraction of steam consumption not depending on the output amounts to about 15 per cent. of the total, and the corresponding figure for coal consumption will be larger still owing to radiation losses, etc. It is hardly necessary to point out that the number of units that could be generated from the amount of coal estimated, as a fixed charge by Manchester depends entirely on the size of the plant and the length of time over which generation has to be extended, so that the figure given is more picturesque than useful in that particular connection. With regard to the author's contention that the tramway department should lay and maintain its own cables, because they should be in a better position to do so, it may be pointed out that the supply department submits the B.O.T. records at present, and it cannot be gainsaid that many tramways have no experienced and responsible engineer. Why should a meter owned by a tramway department be put in series with those of the supply department at intervals to check them? It is no more, perhaps less, likely to be correct than those always in circuit and under constant observation. Why not have three meters constantly in series: one owned by the supply, one by the tramways, and one joint property? For fixing the total maximum demand to be dealt with, it does not matter how often the maximum tramway demands and the maximum lighting demands do not overlap; if they do so once, as on Christmas eve, it is sufficient, and that demand has to be met. It is hoped that the other figures given in the tables are more correct than those quoted for Dundee; the price charged to the tramways for two years back has been 1·125d. not 1·25d., moreover, it should be marked (*d*) as all capital charges on plant and cables, and upkeep on overhead equipment are included. This correction also applies to Table V., and "three cases" should be altered to "four cases." **Mr. Richardson.**

Mr. F. A. Fitzpayne: The price per unit, as shown on Table I., of traction and lighting stations combined, local authority, of 0·93d. paid by the Leith Corporation tramways to the electricity department for the year 1907–8 is incorrect. The correct price was 1·25d. per unit for the first 100,000 units, and thereafter 1·00d. per unit. In the year 1907–8 there was a rebate of £400 granted by the electricity department to this department, as the meters for over two years previous to this were **Mr. Fitzpayne.**

Mr. Fitzpayne.

reading fast. The private power consumers, when the account was £300 and upwards, were charged in 1907–8 1·50d. per unit, less 15 per cent.

Mr. Allan.

Mr. P. F. ALLAN: I should like to take exception to Mr. Yerbury's dictum, that the price at which any commodity can be sold is determined, firstly, by its entire cost of production, and secondly, by the number or quantity sold. I consider that the selling price depends partly on the manufacturing price and partly on the salesman's ability, and to a very large extent on the local and trading conditions and competition.

DISCUSSION AT BIRMINGHAM, FEBRUARY 16, 1910.

Mr. Chattock.

Mr. R. A. CHATTOCK: The paper has evidently been written by a tramway manager who has come to the conclusion that the engineers of combined stations are charging the tramways too much and the power consumers too little for the current which they supply. In my experience of consumers I have never yet found one who admits that he is satisfied, and I suppose that Mr. Yerbury is merely voicing the general feeling. One has, however, to remember that the prices in the sixty-five towns referred to are fixed by committees of hard-headed business men, and it is inconceivable that in every one of these towns the city engineer should be able to persuade them to charge the tramway department more than their fair share. Moreover, these prices have to be agreed to by another committee of equally hard-headed business men who watch over the tramways. Mr. Yerbury has stated that the load factor of a tramway supply is better than that of a power supply. This, however, is not so, the figures in Birmingham for the present year being: Lighting, 10·75 per cent.; power, 34 per cent.; tramways, 27·5 per cent. In addition to this consideration, one must remember that large power consumers are generally supplied with high-tension current at 5,000 or 10,000 volts, while the tramways are supplied at a pressure at 550, which necessitates the use of much heavier and more costly cables. I think Mr. Yerbury's figure of 0·241d. per unit generated given as the interest and sinking fund allowance is too low. I have worked out the Birmingham figure as 0·378d., and I think Mr. Yerbury must have omitted something—possibly the cost of the feeder cable. It may be, however, that Mr. Yerbury has got a very long loan on his feeder cables. I think that the comparative table at the end of the paper is somewhat unfair. The cost in the separate stations does not include depreciation nor, so far as I can see, the interest and sinking fund on the cable, while in the case of the combined station, everything is comprised, including a certain amount of profit, which it is only fair to allow, and which, I think, ought to be at least 5 per cent., and in addition sufficient should be included to allow a sum to be set aside for the reserve fund account. I think it rather a pity that Mr. Yerbury has not made it clear that he is comparing the generating cost of tramway stations with the selling price of combined systems.

Mr. A. M. TAYLOR: I believe it will be found that, in spite of Mr. Yerbury's criticisms, Mr. Pearce's charges are substantially correct, and am very pleased to see that the latter makes an attempt to break up the so-called "works costs" into "running" costs and "standing" costs. The rate per unit at which the consumer is charged should, as far as possible, include only that element of cost which is strictly proportional to the number of units. All other charges should be thrown into a charge which is proportional to kilowatts demanded. Strictly speaking, there should be a third class of charge (see curves which follow), virtually independent both of units and of kilowatts, and of the nature of a Mr. Taylor.

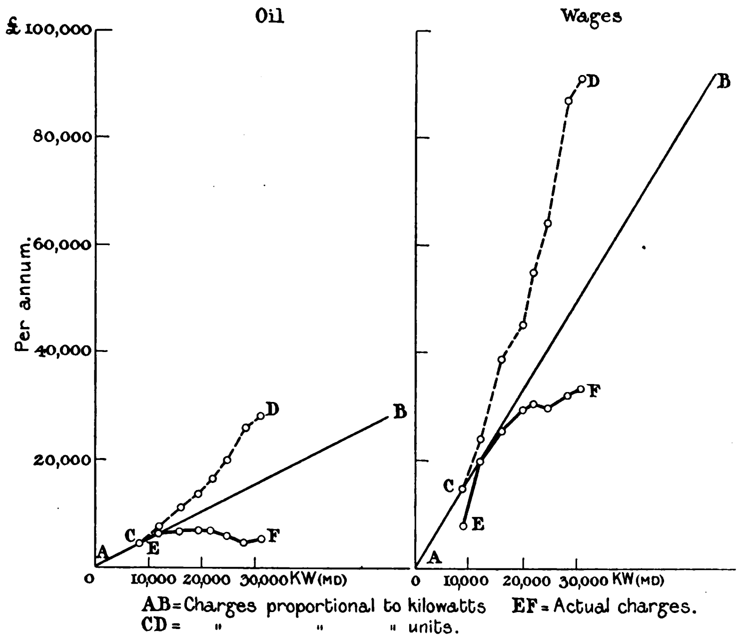

FIG. B.

constant charge; but for the sake of simplicity this may be thrown into the charge made per kilowatt per annum. This is less unfair to the purchaser than to throw it into the charge made per unit. The latter penalises a consumer who has an improving load factor. An example will make this plain. Let us assume, for the sake of argument, that the tramways department is charged on the basis of 0·17d. per unit + £9·45 per kilowatt per annum (see later). This means, on 29½ million units and with 11,200 k.w., a charge of £20,900 + £106,000 = £126,900. If, now, the load factor went up 50 per cent., the total charge would be £137,350. But if charged on a basis of (0·865 + 0·197)

Mr. Taylor.

1·04d. per unit, the tramways department would have had to pay £190,350—that is, they would have been penalised for an improving load factor to the extent of £53,000. The effect of reducing the "running" charge is, of course, to increase the total of the "fixed" charges. Figs. B and C show that, in large stations at least, the oil, wages, and repairs cost are in no sort of proportion to the units sold; and that they are not even in proportion to the kilowatts of maximum demand, but are more nearly a constant quantity. The curves represent the Manchester expenses, as incurred over the last eight years,

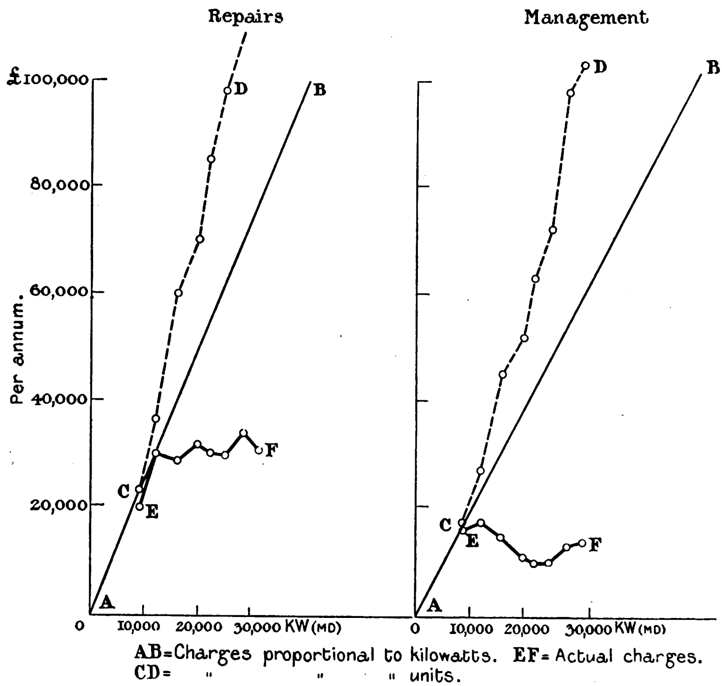

FIG. C.

taken from the published figures. The thin, straight line (A B) on each curve represents the rate at which the charges should grow, if they followed a law of growth in proportion to kilowatts; and the thin curved line (C D) represents that required to follow a law of growth in proportion to units. It will be seen at once how entirely wrong in principle it is to throw oil, wages, or repairs into a charge to be levied on every unit sold.

Taking the "running" charge for coal at 0·17d. per unit (which

allows approximately 4 lbs. of coal per unit sold), the fixed charges for 1907–8 come out as follows :— Mr. Taylor.

	Per Kilowatt per Annum.
	£
Standby coal	0·74
Oil	0·18
Wages	1·11
Repairs	1·20
Rates	1·02
Management	0·46
Interest and Sinking Fund	5·12
Reserve and depreciation	2·09
Total	11·92

With the exception of the last two items there is very little difference for the year 1908–9; and if the charges per kilowatt be plotted with kilowatts, it will be seen that the annual diminution is, on a station of this size, very small. If we take it that the Manchester tramway load has a load factor of 30 per cent., giving a maximum demand of 11,200 k.w. for 29½ million units, the fixed charges levied on the tramways at Manchester become :—

	Per Kilowatt.
	£
Coal (standby)	0·47
Oil, etc.	0·04
Wages	0·75
Repairs	0·70
Rates, etc.	0·95
Management, etc.	0·39
Interest, etc.	4·82
Reserves or depreciation	1·32
Total	9·45

(Per kilowatt of maximum demand per annum.)

I therefore think that, considering that Mr. Pearce's fixed charges for the general supply were some £12 per annum per kilowatt, he was justified in charging the tramways department £9·45 per annum per kilowatt, this latter giving a difference of some £2½ per annum per kilowatt, as a reduction on account of those expenses not incurred in connection with tramway supply.

Mr. H. Jackson: Judging from the paper, it seems to me that the law of supply and demand is to be thrown overboard altogether by tramway managers, and charges for current are to be based not upon the profit-earning power of the electricity department, but simply on the most economical conditions under which the electricity department can be run. The figure mentioned by Mr. Yerbury as being the profit that should be added before the charge is made to the tramway depart-

Mr. Jackson. ment, is from 3 to 5 per cent. on the total costs, but why should it not be something higher? If there is any economical advantage in the running of any electricity department, why should not the department have some advantage from it? It seems to me that an actual 5 per cent. on the running costs is not really sufficient for an economical working of the electricity department. Of course, Mr. Yerbury might say that if the tramway department runs its own station it will be able to do without earning any profits. This is exactly the position. But if it is a profitable concern instead of a municipal undertaking, it will have to be earning not merely 5 per cent. on its running powers; the percentage will have to be on its outlay, on its capital. Mr. Yerbury's contention, whilst very good from the tramway engineer's point of view, is not altogether fair from that of the electricity department. I should like to express my appreciation of the point brought out by Mr. Taylor, and I quite agree that the standing charges ought to be separated in the way that Mr. Taylor has indicated.

Mr. Yerbury. Mr. H. E. YERBURY (*in reply*): Mr. Snell objects to my general statement on page 586 that "Tramway departments have to pay costs which legitimately belong to the lighting and power departments." Personally, I am strongly of the opinion that tramway departments should not be burdened with capital charges incidental to the plant and high service charges of the general supply department. It is well known that ordinary services cost from £5 to £20 per service, and in some cities where there are, say, between 3,000 and 4,000 consumers, you may have a capital expenditure of over £40,000 under that heading. In my opinion it is unfair to expect tramway departments to pay the standing charges on that expenditure.

Mr. Snell. Mr. SNELL: I think you have misunderstood me. I expressly excluded mains and services in the calculation. I quite agree that tramways ought not to pay either on mains or services.

Mr. Yerbury. Mr. YERBURY: But they do.

Mr. Snell. Mr. SNELL: I thought you were attacking my remarks.

Mr. Yerbury. Mr. YERBURY: You suggested that the capital charges should be pooled.

Mr. Snell. Mr. SNELL: The capital charges of the generating station.

Mr. Yerbury. Mr. YERBURY: It appears that this is what is done in Bradford and Manchester, but they also include mains and services, which, I say, "legitimately belong only to the lighting and power departments." According to the statement some years ago of the manager of the Manchester Tramways, the standing charges per kilowatt debited to the tramways department amounted to nearly £12, almost 1d. per unit. We will take the self-contained systems of Leeds and Glasgow. I am very pleased that Glasgow has been mentioned, because Mr. Snell suggests that I am comparing low-tension with high-tension systems. I have had some figures with regard to Glasgow given me within the last month, and I find there that their standing charges per kilowatt installed amount to £3 5s. 5d., and per unit generated 0·391d., and coming down to the direct-current traction side—*i.e.*, from the sub-

station direct-current busbars—their standing charges per unit are 0·41d. At Leeds, which is also a high-tension station, their standing charges per kilowatt installed amount to £4 1s. 3d., and per unit generated 0·386d., and on the direct-current traction side 0·402d. The total costs in Glasgow are high compared with some other cities owing to the large amount expended in buildings, etc., and their exceptionally high depreciation account, amounting to more than £54,000 per annum, or 0·470d. per unit generated. Assuming that fixed charges were based only on plant required for tramway supply, there was no reason why a combined undertaking should not supply power to tramway departments at the same rate as the latter could generate at, and this should leave a fair margin of profit. If, on the other hand, the fixed charges incidental to the entire undertaking are debited to the tramways in proportion to their requirements in kilowatts, then I have no hesitation in saying that tramways would be more economically run as entirely self-contained undertakings. It was well known that in high-tension stations losses in transmission and conversion were far greater than in low-tension stations. For instance, at Sheffield the standing charges per unit generated were 0·269d., and on the basis of units taken by cars, 0·295d. At Manchester, which was a combined station generating over 82 million units per annum, their standing charges amount to 0·503d. per unit generated—*i.e.*, total output of the station. They knew theoretically that the total costs should be very much lower in combined stations than in separate stations, but in practice this was found not to be so, and the tables in the paper showed that the costs were very much higher. I have endeavoured to differentiate between different size stations by only including those in Table V. generating above 2 million units per annum. A much stronger case could have been presented had I included small systems—Dover, for instance, where 2·75d. per unit is charged to the tramways. Mr. Snell's suggestions as to a fair basis for charging appeared to be a great improvement on existing methods of computation. I disagree with Mr. Snell that there is a greater loss to municipalities where two stations are built, as local rates have been and are being relieved to a far greater extent by self-contained tramway undertakings. Mr. Yerbury.

Mr. Stuart Russell spoke in respect to the items which, in his opinion, should be included in fixed and running charges. He is doubtless unfamiliar with the Tramways Standard Form of Accounts which was drawn up and agreed upon by all municipal tramway managers. Whilst I agree that radiation losses are a fixed charge on a station, the total quantity of coal consumed covered all losses, and should be chargeable to works costs. If not, why were not ordinary power consumers charged also with this so-called fixed cost? In respect to his criticism of certain figures shown in the paper, the only Manchester figures available for dissection were for 1907 and 1908, when 1·143d. per unit was charged to the tramways, whereas the figures for Sheffield and those in the tables were for 1909. These dates are given in the paper.

Mr. Yerbury.

In reply to Mr. Cowan's remarks and the postulate he enunciated, I certainly feel proud of the fact that I deal with a very high class 18-carat traction current. I was not aware before that one could differentiate between power used for tramway purposes and for other purposes. I was always of opinion that electricity was the same, no matter what use was made of it. Respecting his postulated principle wherein he says that any monopolist element should be excluded, I venture to think that the high price frequently charged to tramways is due to the combined undertakings having the monopoly and exercising it to their advantage.

Mr. Shaw says I deal chiefly with the figures of two large undertakings. That is so, but only in order to dissect costs in each case, and I submit that the suggested basis of charge is applicable to small as well as large undertakings. I agree with his remarks that in small undertakings there are violent fluctuating loads, and the bigger the system and the larger number of cars running, peaks become flattened out, and you get a steadier load, as shown, for instance, on the load curves in the paper. I was rather surprised to hear him say that the coal per unit for traction purposes was higher than for general lighting and power supply. It seems to me that when he has a load factor of 26 per cent. on his traction side his coal costs should not be higher than on a power load of 20 per cent. to 25 per cent., as the former is a long-hour consumer.

Mr. Wordingham spoke of combined stations from the standpoint of a municipality as a whole. I am not dealing with the question purely from a municipal standpoint. I have come down in this paper to absolute £ s. d. figures, and you find that in the summary at the end of Table V. the mean of the total generating costs of the whole of the stations, both low-tension tramway stations and high-tension tramway stations, is about 0·75d. per unit. The mean price charged to tramway departments in the seventeen stations that supply over 100 million units per annum is about 1·2d. per unit. I quite agree with Mr. Wordingham that there should be a saving by the acquisition of a tramway load to a combined undertaking; but if there is that saving it was not reflected in the price charged to the tramway departments. In respect to standing charges on fuel and oil, etc., it was very difficult to estimate what this amounted to for different customers, and all should be included in works costs, on which it was suggested that profits of, say, 3 per cent. to 5 per cent. should be charged to tramway departments.

In reply to Mr. Bond's comments, I am pleased to hear him say that arbitrators should have some broad principles on which an equitable basis of charge can be determined, and I agree that at the present moment there is no broad recognised principle. It is gratifying for me to hear that he himself would be prepared to agree to the principles set out in the paper. I agree that the total cost of production should not be higher from a combined station than from a separate tramways station built by a company. For instance, if we in Sheffield had paid the same price per unit as, say, the Manchester or Bradford depart-

ments, or even 1d. per unit, there would have been nothing to hand over to relief of rates, and in some years a loss would have been entailed; whereas during the past ten years the average relief of rates from the Sheffield tramways amounted to over £14,000 per annum. The percentage of management charges in combined undertakings, together with salaries and wages of running and maintenance staff, usually amount to between 30 per cent. and 35 per cent. of the total generation and distribution costs, presumably due to the salaries of collectors and clerical staff and the large quantity of printing required, whereas in separate tramway departments these charges only amount to about 20 per cent. of the total cost; and I contend that tramway departments should not be charged *pro rata* with general supply departments, but only on a predetermined proportion to be agreed upon, based on a kilowatt capacity of the tramway plant. Mr. Yerbury.

In reply to Mr. Shawfield, I do not say anywhere in the paper that tramways should be charged as low a rate as ordinary power consumers, as I am of opinion that in many instances the rate to power users is too low. It was, of course, admitted that modern stations could be equipped far cheaper than old-fashioned ones, and the question was whether it was just and fair to charge new consumers less than old consumers who had assisted in building up the undertaking. As to the question of depreciation and obsolescence, I am quite prepared to have my figures, 1·75 per cent. per annum, criticised, for it must be remembered that during, say, the first five years' life of undertakings no money was required for renewals. On the Sheffield tramway system renewals of power station plant and cables during the past ten years never amounted in any one year to more than approximately £1,000, and the average for the ten years had been £450 per annum, so that on a capital expenditure of, say, £260,000 for plant and cables, 1·75 per cent., with the balance already in hand, would be ample for extraordinary renewals and obsolescence. We have an accumulated surplus and renewals fund amounting to over £92,000, or nearly 8 per cent. of the total gross expenditure of the undertaking, and I contend that present ratepayers should be relieved as much as possible, and that posterity should not be in the happy position of having a substantial balance at the bank in addition to a valuable asset in buildings, plant, and cables at the expiration of the loan period.

I am in full agreement with the principle enunciated by Mr. Bromley Holmes, viz., that the existence of combined stations is only justified if each service is benefited by the combination. I note that he also condemns the sale of electrical energy to any consumer below the total cost price of production. In respect to the setting out and maintenance of cables, the recommendations made in the paper were to overcome the feeling of many tramway managers as to excessive losses in transmission, etc. In many cases it would doubtless be satisfactory if all cables were maintained by the supply department. It is quite true that local conditions vary widely, but these do not appreciably affect the broad basis of charge as set out in the paper.

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In respect to the observations of Mr. Fedden, opinions differ as to all corporation undertakings (in one city) being really one business, and I venture to express the opinion that each department should be separate and be administered on sound commercial lines. Mr. Cridge enlightened me as to daylight consumers on his mains having a discount up to 50 per cent. from the ordinary price of 4d. per unit. I suggest that the words "daylight consumer" imply that in proportion to the general body of consumers the number must be infinitesimal. I am surprised he should give me a reminder that our own car shed is supplied at 1½d. per unit from his department, for he must be well aware that we consented to pay more than double our own cost of supply after the special pleading from his department and from members of his committee for our assistance in paying standing charges on a lightly loaded cable in that district. He practically admits that his power consumers are not charged a proportion of the capital expenditure on the entire undertaking, but only on the plant installed at his new station. This policy undoubtedly brings in additional revenue, but it appears to me to be hardly fair to many consumers, who get no reduction in price per unit, although the generating costs have been reduced more than 50 per cent. by the acquisition of this power load. I observe there is a droop on the lighting and heating load curve and a rise in the curve for the power load on his system, which means that the lighting consumers will not get any reduction, for they will always be burdened with high capital charges, and I certainly think it an unjust policy to charge a lower rate to new consumers as he suggested. In respect to the offer to supply high-tension current at 0·55d. per unit, I have no hesitation in saying that it would not pay us to accept it, as we should have to instal high-tension apparatus and transforming plant, the loss on which would be approximately 20 per cent., which would certainly bring the figure up to more than our total costs of 0·659d. per unit. He suggests with regard to our peaks that he has seen rather different peaks when he has visited the station. Perhaps at the time that he visited the works the circuit breakers were coming out, but I can assure him that the charts submitted have not been specially chosen for the paper. I am in full agreement with Mr. Wardale's comments relative to proposed preferential tariff, and I contend that if total works costs are reduced by, say, a good power load, that all consumers should have some benefit, and not only the later ones connected to the supply. Mr. Acland mentioned peak loads. It is well-known that the larger the undertaking the less violent is the fluctuation on the tramway load. With a greater number of cars in service peaks become flattened out, and I have no doubt that he gets more varied peaks than we should get. Throughout the paper I am only dealing with what may be called moderate-sized systems that require over 2 million units per annum. I was pleased to hear that he had worked out on his system the selling price in accordance with the suggestions in the paper, and that it

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amounted to 1·1d. per unit as against 1·25d. charged to his tramways department. Mr. Fawcett remarked that 3 to 5 per cent. profit is very small. I may say that in Manchester and also in Bradford the percentage of profit determined by the supply department is 3 per cent. only on their works costs, which brings in a return at Manchester of approximately £1,000 per annum. In a separate tramway station the fixed charges are approximately the same as the total works costs per unit, whereas in a combined station standing charges are often double the total works costs. Mr. Councillor W. C. Fenton rightly upholds municipal ethics, and I thank him for his comments on the paper. Mr. Dickinson referred to the maximum demand. I say that the charges should be based on the maximum demand of the consumer in all cases, because the maximum demand determines the amount of plant required (together with the spares) to provide that consumer with the current that he requires. With respect to the phraseology in one or two of the sentences in the paper, I simply put it forward that the generation of electricity is the same, no matter what use is made of it. I do not say that it has no greater value for any specific purpose. The text of his comments appears to me to be the policy of "get all you can." It is a very businesslike policy, I admit, but at the same time I fail to see why there should be such a great difference made between the respective customers. For instance, the price charged per unit to tramway departments varies to an enormous extent. Take Stalybridge; they charge no less than 170 per cent. above their total works costs (including management, rent, rates, and taxes) to the tramways department. In Halifax the tramways department is debited with 10·5 per cent. in excess of the total works costs. I suggest that there is not that great difference in interest and sinking fund charges between these two places to justify that great difference in selling price. In one case you have a reasonable 10·5 per cent., and in the other 170 per cent. Mr. Dickinson also referred to the load charts, and I must point out that the peaks are dependent on the car service. Wherever you see a high peak load, this is invariably brought about by the number of cars running at that time. The 188 cars mentioned in chart A were, of course, not in service throughout the whole of the day, as "specials" are brought out in the early morning, at noon, and in the evening. The maximum demand is determined by the maximum peak load at any time, and I suggest 25 per cent. spare plant as against an average of 33 per cent. now in combined stations. Mr. King in his communication points out the ratio of price charged per unit to seventeen tramway undertakings to their respective "total works costs." There is no doubt, as I said before, they vary enormously. The lowest is Dundee, which seems to me to be very reasonable—viz., 9 per cent. above the total works costs—and the highest is the one mentioned, 170 per cent., which appears to fully bear out Mr. Dickinson's text, "Get all you can." I am pleased to hear Mr. Rogerson say that he agrees with the general principles set out in the paper, and I think in his allocation of the price charged to his tramways, that he is very reasonable in that he only debits

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them with 10·5 per cent. of his total works costs. I was interested to hear that he has gone into the question of determining the price in accordance with the suggestions in my paper, and that they work out very near to the actual figure which he debits to his tramways department. Respecting the load charts on his tramways, I have no doubt that if he had another 50 cars on his system his peaks would be flattened out somewhat, and he would not get the fluctuations which are shown at the present time. I agree with him that a broad basis on which charges should be made could very well be framed by the Municipal Tramways Association and the Municipal Electrical Association.

Mr. Pearce comments on the Standard Form of Tramway Accounts and the tables submitted in the paper. It must be understood that these accounts were framed to be comparable with the Board of Trade model accounts relating to supply departments where generation and distribution costs are included in "total costs." Although the published data respecting various undertakings are dissimilar, from a tramway manager's point of view, he knows from actual figures what his costs would be if he generated his own supply, and he is therefore unconcerned as to whether his energy has to be, say, transformed or supplied direct from the combined station. The success or failure of tramway undertakings is largely determined by the price of electrical energy. Mr. Pearce criticises our 1908 total costs—viz., 0·668d. per unit generated, and quotes a letter sent to the *Electrical Review*, wherein I pointed out that his method of comparison between Manchester and Sheffield was not quite fair. He says the Sheffield total of 0·66d. amounts to 0·81d. if put on the same basis as his own station, and he associates my name with some correspondence he had with the general manager of the Sheffield tramways when the total cost per unit of 0·81d. was assumed. I was not consulted over that correspondence, and the figure assumed is erroneous, for the following reason: Mr. Pearce deducts the whole of the units taken in the power station from the tramway load. Now we use about 150,000 units per annum for boosting purposes, and when these are included in traction units—and I believe that Mr. Pearce will agree that they should be chargeable to traffic for traction purposes—his 0·81d. is reduced to 0·75d., which covers all rates and taxes on ducts and cables, also income tax, and his own estimate of 12 per cent. loss on our mains. Now, assuming his charge was 0·75d. to the Manchester Tramways Department instead of 1·143d. for the year under review, his revenue would have been reduced to the amount of £48,306 5s. Mr. Pearce honours me by saying he has read the paper through two or three times, but he says he was very surprised not to find any reference to Glasgow. He will find by consulting Table II., page 589, that Glasgow works costs are 0·350d., and total costs 0·75d. per unit generated. Although Mr. Pearce says he has gone into the comparison of Glasgow and Manchester very carefully, and finds Glasgow's figure is 1·14d., as against his figure of 1·04d. for 1909, and 1·143d. charged in

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1908, he is silent as to how the total of 1·14d. in Glasgow is made up. I find on closely examining the respective accounts they are not strictly comparable, as Mr. Pearce suggests, for variations are apparent in interest and sinking fund obligations, 2 per cent. Glasgow, 2¾ per cent. Manchester, and the depreciation account for Glasgow is 4·9 per cent. as compared with 1·68 per cent. for Manchester, and Glasgow rates and taxes are 1·5 per cent., and Manchester 0·92 per cent. The Glasgow figure of 1·14d. per unit is therefore made up of total costs, including all standing charges 0·75d., plus depreciation account of 0·47d. The standing charges per unit on the direct-current traction busbars at Glasgow = 0·410d., and per kilowatt installed £3 5s. 5d. In Manchester, according to the statement of the tramways manager a few years ago, the standing charges per kilowatt installed debited to tramways amount to nearly £12 (almost 1d. per unit), and I find that on Mr. Pearce's total output of over 82 million units per annum his standing charges = 0·503d., yet he contends that the above two systems are fairly comparable. The question of units generated and units sold has been mentioned. I suggest that 10 per cent. should be the maximum to cover the difference between gross output and units taken by cars and depôts, whereas in a combined undertaking, if transformation is necessary, a loss of at least 20 per cent. may be expected; but in the case of Leeds and Glasgow tramway stations where high-tension plant is installed, the total cost from the direct-current side of station (net output) only amount to 0·798d., which figure includes proportion of taxes, insurance, and general management. Mr. Pearce says he considers fixed charges should be pooled. I say this is a wicked policy so far as tramways are concerned, for, taking service charges, where an ordinary service costs from £8 to £10, and large services amount to nearly £20, assuming there are 3,000 to 4,000 consumers, a capital expenditure of over £40,000 may be entailed, and it is, in my opinion, unfair to expect tramway departments to pay standing charges on this expenditure. In self-contained high-tension systems, say Leeds and Glasgow, standing charges amount to £4 1s. 3d. and £3 5s. 5d. respectively, which equals 0·40d. per unit on the direct-current traction side. Assuming that fixed charges are based only on plant required for tramway supply, there is no reason why a combined undertaking should not supply electrical energy to tramway departments at the same price as they themselves could generate for, and this should leave a fair margin of profit; but if the fixed charges incidental to the entire undertaking are debited to a tramways department in proportion to their requirements in kilowatts, then I say tramways would be more economically run as entirely self-contained undertakings.

Regarding peak loads, they have not been ignored in the paper, for it is suggested that 25 per cent. spare plant should be allowed on the top of maximum peaks and that the tramway departments should pay for this plant. Mr. Pearce upholds his policy of debiting to standing charges, coal, oil, wages, etc. It appears to me that engineers

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of combined stations have nothing to lose if all fuel, etc., is charged to works costs, on which I recommend a profit of 3 to 5 per cent. Mr. Pearce criticises my 1·75 per cent. for depreciation and obsolescence, but it must be remembered that during, say, the first five years' life of undertakings no money is required for renewals, therefore a substantial nucleus is available with accumulated interest for later years. In Sheffield we have at the present time an accumulated surplus and renewals fund amounting to over £92,000, or nearly 8 per cent. of the total gross expenditure of the undertaking, and I contend that present ratepayers should be relieved as much as possible. We find that by putting aside 1·89 per cent. per annum of our total capital expenditure, we have been able to renew many miles of track and also renew a large number of car equipments and car bodies, so that I consider a percentage of 1·75 is ample for generating plant and cables which undoubtedly have a longer life than, say, tramway rails and cars. Although, as Mr. Pearce points out, the suggested percentage gives an equated life of thirty-four years, it is not essential for life to be sustained for that period, but only during the loan period, which averages about twenty-five years. I was interested to hear Mr. Salter's remarks, as he is a buyer. I find he is in agreement with the main points set out in the paper, and he emphasises by actual figures my contention that a tramway load is of exceptional value to a combined station, hence the department providing that ideal load should not be overcharged. From a buyer's standpoint I appreciate his remarks, that he wants a reasonable price charged and is prepared to ignore all "scientific principles." He has my sympathy in fearing to send out additional cars on Bank Holidays owing to the maximum demand increasing his annual capital charges.

In reply to Mr. Atchison, as mentioned in the paper, small stations were not included. It is admitted there are more distinct peaks where few cars are in service, but I disagree that there are any places where tramways are supplied from combined stations at a loss. I could enumerate many instances of tramway undertakings working at a loss, due to high cost of power. It was interesting to hear Mr. Stewart's remarks about his load factor being often a negative one, brought about by regenerative control. It would be very difficult to carry out Mr. Stewart's suggestion, that the portion of load curve representing a "fringe" should be charged for at a relatively higher rate, for often a peak or excessive fringe is brought about by a block in traffic or other circumstances over which the tramways department have no control.

Mr. Miles Walker brings forward an important matter on which engineers of combined systems are always silent, viz., the advantageous power factor which is often attained by the acquisition of a tramway load, and I agree that a concession should be made where a tramway supply improves the power factor of the whole station.

Mr. Whysall sums up the matter very wisely when he says that there should be an attempt made to satisfy the departments on a fair and equitable basis. Respecting Mr. Watson's remarks relative to fuel

and stores being looked upon as fixed charges, radiation losses, etc., were, of course, a charge on the station, but cannot be allocated to different consumers, hence I suggest that all should be included in running costs on which a profit of 3 to 5 per cent. is recommended. I was very pleased to hear that Mr. Watson deducted certain costs connected with consumers' accounts and mains, and also capital charges before deciding on the charge to his tramways department. The ratio of price charged to total works costs (less interest and sinking fund) on the fourteen consumers included in the tables vary considerably, the greatest difference being at Stalybridge, where 170 per cent. excess of total works costs is charged to the tramways department, compared with a reasonable 9 per cent. at Dundee. It need hardly be said that the former tramways system is run at a loss, and the latter undertaking at a profit. Mr. Watson points out the cost of power generated at the Blackpool and Fleetwood Tramway Company's station and the Blackpool Corporation station. He has certainly chosen a most favourable station for comparison, for it is well known that the former contains obsolete plant, and I believe the boiler pressure is 120 lbs., whereas the latter station has been brought up to date. In the case of Hull, the total costs in the tramways station, including standing charges, are 0·825d., and in the lighting and power station the total costs are about 1·2d. per unit. Birkenhead has been mentioned, where there are either two or three generating stations, and, I believe, owing to high standing charges their costs are about 1·2d. per unit. I can, therefore, hardly agree with Mr. Watson that the above are "fairly typical examples of small tramway undertakings." He will not admit that there are extraneous and incidental advantages which a tramway supply gives to a combined station, and he therefore thinks that my proposed profit of 3 to 5 per cent. is too small. If I myself failed to see the advantages accruing from a tramway customer, I should propose a somewhat higher percentage of profit, but I can assure Mr. Watson that there are many combined stations quite satisfied with 3 per cent. profit, and many other stations where a tramway supply would be welcomed at only total works costs, for the incidental advantages are invariably recognised, and an instance is given by Mr. Salter where the Heywood Corporation costs were 4·19d. per unit, but when they supplied the tramways their generating costs were reduced to 1·23d. In reply to his question, as stated in the paper, the figures in the tables are based on units generated in separate tramway stations and price per unit sold in combined stations. Mr. Yerbury.

Professor Baily speaks of the theory and practice of "dumping." Permit me to say at the outset that I am preaching tramway tariff reform. Professor Baily says that old lighting consumers are in no way injured by lighting consumers obtaining a revised tariff, but it appears to me that if total costs of production are reduced by any means, all consumers should have equal treatment and obtain the benefit of such reduction. I am glad to hear that he considers my proposed method of allocating

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costs very moderate, and it remains to be seen whether engineers of combined stations concur in such recommendations. In reply to Mr. Robertson, I appreciate his remarks relative to small systems with very fluctuating loads, but even these conditions do not affect the broad principles set out in the paper. In respect to a tramway having no diversity factor, doubtless Mr. Robertson would think otherwise if he were in charge of a station when, through a block in traffic, or heavy snowstorm, several hundred cars were disorganised. With regard to Glasgow's depreciation account, it is well known that it is the highest in the country, but it must be remembered that the situation in Glasgow is peculiar compared with all other cities working tramway undertakings under ordinary Parliamentary powers. In reply to Mr. Neilson regarding costs of generating station on page 594, these figures were only used to show the difference in capital cost of combined and separate tramway stations and the standing charges of the former compared with the latter, which charges materially affect the price charged to tramway departments. Mr. Lackie expresses his regret that a more definite conclusion has not been come to in the paper. I say, if the suggestions put forward in the paper are carried out by supply departments, the result will be definite and satisfactory from the consumer's standpoint. In respect to the allocation of fixed charges and running costs in the summary, it will be seen that salaries and wages of staff and repairs to plant and cables, etc., are included in running charges, and not in standing charges as stated by Mr. Lackie. He suggests that separate plant has to be allotted for supplying tramway departments. This is admitted in many instances, and it is recommended in the paper that the total cost of this plant should be borne by the tramways department. But as separate plant and accessories are required for general supply, the cost of this plant should not be inflicted on a department which does not require such plant. Mr. Lackie has evidently misread many points in the paper, especially as he interprets the sentence, "No hard-and-fast rule can be laid down as so much depends on local circumstances" to apply to the general question, whereas this remark appears in Clause 4 in the summary relating to depreciation, renewals, and obsolescence. I must therefore return the compliment and say that Mr. Lackie has given his whole case away, and I can assure him that the figures given for Glasgow are quite correct and have since been verified by the tramways general manager and appear in the published accounts. He is quite correct in saying that the total costs are 1·227d., but he is silent as to how this total is made up. It is distinctly stated in the paper that the total costs in separate stations do not include depreciation allowance, as this varies in every town; and excluding this item, the figure for Glasgow, 0·75d. per unit generated, is the total works costs including interest and sinking fund on the total capital expenditure on buildings, plant, and mains, etc. As over £54,000 per annum is set aside for depreciation, this works out to about 0·470d. per unit on the total number of

units issued from the power station to sub-stations. This, by the way, is a far larger percentage for depreciation than in any other undertaking. Mr. Lackie's total of 1·227d. is therefore made up of their total costs, 0·750d., and depreciation allowance, 0·470d. I am surprised to hear Mr. Lackie say that the running costs of a high-tension supply with sub-station machinery are not higher than a low-tension system. I am waiting to see figures bearing out his opinion in that respect. He further criticises comparative costs of the two systems, Bradford and Sheffield, on page 588, and says they are "thoroughly unsatisfactory." In this opinion he has an out-and-out supporter in the general manager of the Bradford tramways. The maximum demand is approximately the same on each system, and the load factor of the Bradford high-tension station is about 29 per cent. Respecting interest and sinking fund at Sheffield, it averages 5·18 per cent.; at Bradford it averages 6 per cent. Mr. Lackie recommends a total, including reserve, of 8 per cent., and we in Sheffield allow 7·07 per cent., as stated quite clearly in the paper. Mr. Yerbury.

In answer to Mr. MacMillan as to whether the question for solution is an engineering or a commercial one, I contend that it must be considered conjointly. He asks for a clear explanation as to why combined stations fail to yield the proper supply of units at as reasonable a price as the separate stations. There is no difficulty in answering that question, although his analogy of bargain sales, in my opinion, is not germane to the subject matter. In order to compare the present selling price with the total generating costs in tramway stations, one has only to consider capital expenditure on machinery, auxiliaries, mains, and services required for, say, lighting consumers. At the present time tramways are being charged a proportion of these uncalled-for costs under the admitted pooling system; and I say, if tramways are charged only on the basis set out in the summary in the paper, that combined stations could show, in an unassailable manner, that power for tramways can be sold as cheaply as from a separate tramway station. These remarks apply to Mr. McMahon's comments, and I am glad to have his Northampton figures, which clearly show that if only suitable and necessary plant is installed for tramway supply, the selling price should be within, or not more than, 1d. per unit even in small stations.

It is refreshing to hear Mr. Burbidge say that as engineer of a combined undertaking supplying tramways, he finds it difficult to criticise the paper. The vexed question of the accuracy of meters should be left for engineers to settle, for it is amusing to hear the complaint of some non-technical tramway managers as to increase in units per car-mile, when on investigation it has been found to be frequently caused by increase in speed of cars, due either to higher voltage or, may be, larger diameter wheels, or due to heavier cars or more passengers carried, and many other causes. I am obliged to Mr. Richardson and Mr. Fitzpayne for drawing my attention to errors in their respective power prices as shown in the tables, and with these two exceptions I believe the figures are correct.

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Notwithstanding Mr. Chattock's remarks concerning hard-headed business men on committees settling the price to charge various consumers, it is well known that even these gentlemen are advised and led by their experts. I do not say in the paper that the load factor of tramways is better than that of power supply. I admit that for a 550-volt supply larger cables are required than for a high-tension power supply, and the entire cost of all ducts and cables as recommended in the paper should be charged to the tramways department. I can assure Mr. Chattock that nothing has been omitted in calculating interest and sinking fund charge amounting to 0·241d. per unit generated on the Sheffield tramways. The loans were originally for 30 years, and are now reduced to 20 years, so that over the full period the charge works out to 5·18 per cent. I can quite understand that his charges amount to 0·378d., and there is no doubt in my mind that the high price charged to tramway departments is very largely due to the high interest and sinking fund charges of combined undertakings. If instead of pooling all charges, as is done at the present time, tramways are only debited with legitimate costs incidental to their supply, then interest and sinking fund should be well within 0·3d. per unit sold.

In respect to the proposed percentage of profit which Mr. Chattock has criticised, I must not suggest that there is a coefficient of moral elasticity amongst engineers of combined stations, still I find that Mr. Chattock charges the tramways 76 per cent. above his total works costs, which price amounts to more than double the total costs in Sheffield.

I regret to say that much irrelevant matter has been introduced in the discussion on this paper, and only two engineers have so far taken the trouble to work out a selling basis on the lines suggested, the engineer at Chesterfield making it 1·1d. per unit as against 1·25d. charged; and at Halifax 1·32d. per unit, as against $1\frac{1}{16}$d. charged. It is very significant that at both of these towns the tramways and lighting departments are under the same management, hence the reasonable percentage of profit, roughly, 10 per cent. above total works costs. At Bradford and Manchester 3 per cent. profit on works costs is considered fair and reasonable, but I am more generous and suggest up to 5 per cent., not forgetting the undoubted advantages which a tramway load brings to a combined station.

As regards the tables of power charges, the costs in separate stations include interest and sinking fund charges on all ducts and cables, and all other charges with the exception of depreciation, and I venture to think that the tables show quite clearly the comparison between separate tramway stations and the prices charged from combined stations.

In reply to Mr. A. M. Taylor, I agree that the rate per unit which a consumer is charged should include only that element of cost proportional to the number of units sold, and the standing charges should be proportional to the total kilowatts demanded; but I do not agree that Mr. Pearce's charges in Manchester are substantially

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correct. The running costs are correct and satisfactory to all concerned, but the pooling of all capital charges on the entire undertaking is unfair to a tramways department. The curves exhibited by Mr. Taylor are very interesting, but all tramway managers are now working to a standard form of account in which coal, oil, waste, water, and so on, are all included in works costs. It has never been suggested that all running costs are in direct proportion to the units generated or sold, or even to the kilowatts demanded, and these points are clearly shown in Fig. 1 in the paper. For instance, if coal was the same price each year, the running or works costs would closely follow the hyperbolic curve on an annual increased output. Mr. Taylor evidently considers that the Manchester charges are equitable, and that Mr. Pearce is justified in charging the tramways department £9·45 per annum per kilowatt of maximum demand as a standing charge in addition to running costs. I can only say that this "scientific principle," as Mr. Salter called it at the Manchester meeting, would, if universally carried into effect, mean bankruptcy to very many tramway undertakings. In self-contained systems the standing charges are a little over £3 per kilowatt installed (including spares) and the total running charges or works costs about £5 per kilowatt installed, making a total of about £8. It will therefore be readily seen that tramways generating their own power are very well satisfied at the economical result. Mr. Taylor mentions 4 lbs. of coal per unit. This is high for large stations. In Sheffield the coal consumed works out from 3·6 to 3·7 lbs.

Mr. H. Jackson's comments on the question of supply and demand appear to be more applicable to a company than a municipality. Of course, the conditions of working are altogether different from a company standpoint, for not only is a reasonable dividend expected by the shareholders, but sufficient must be set aside for depreciation, renewals, and obsolescence for an indefinite period, whereas in a municipal undertaking everything might be scrapped at the expiration of the period of loan and fresh borrowing powers obtained. He appears to forget that nearly 6 per cent. is required to be set aside annually by a municipal undertaking before any so-called profit is made, and he does not appreciate the fact the position of a combined undertaking is immensely improved by the acquisition of a tramway load, for total works costs have thereby frequently been reduced from 60 to 90 per cent., consequently it would be unfair to charge a tramways department more than, say, a 5 per cent. profit. It is well known that the financial obligations of many of the 94 municipal tramway systems cannot be annually met, and that instead of being a benefit to the community, they are, or will be, a burden on the rates. In my opinion there is no hope of retrenchment on such systems where the cost of electrical energy amounts from 2½d. to over 3d. per car-mile.

The President.

The President: I beg to propose a hearty vote of thanks to Mr. Yerbury for his interesting paper.

The resolution of thanks was carried with acclamation.

AN ELECTRICAL SAFETY SYSTEM FOR USE IN MINES.

By H. J. FISHER, Associate Member.

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Although stringent rules have been issued by the Home Office to safeguard persons from shock through contact with metallic sheathings of cables, the framework of motors, and other appliances at times when faults exist on them, it is to be regretted that there have been many fatal accidents, severe shocks, and burns, due to inefficient earthing or due to an earth wire being broken or detached by accident. The majority of accidents of this kind have occurred on portable machinery such as coal-cutters, conveyors, etc., these machines and the cables connected to them having to stand an exceptional amount of wear and tear and rough usage. In fact, it may be said that the conditions are more adverse to safety than on any other class of machinery.

As will be seen from the following rule extracted from the "Special Rules for the Installation and Use of Electricity in Mines," at present the Home Office do not enforce the earthing of coal-cutters, portable motors, and trailing cables :—

> "All metallic coverings, armouring of cables, *other than trailing cables*, and the frames and bed-plates of generators, transformers, and motors *other than portable motors* shall, as far as is reasonably practicable, be efficiently earthed where the pressure at the terminals where the electricity is used exceeds the limits of low pressure."

In many cases, however, the framework is earthed through the metallic sheathing of the trailing cable or, better still, a special core is sometimes inserted in the trailing cable as an earth wire. The earth conductor thus provided, however, is very liable to be damaged, and it has to be admitted that, in many cases, the connections have been made so crude and dependent upon the exercising of such care on the part of the attendant, that the use of an earth wire is no guarantee of safety. This has unfortunately been proved by the occurrence of several accidents. In the cases which have come under the author's notice the coal-cutter machines jammed the trailing cables against a prop, causing one of the cores of the cables to make contact with the framework of the machines, and so in both cases the earth circuit was not intact and fatal accidents occurred.

A type of plug has been commonly used for connecting the trailing

cable to the machine at one end and the gate-end panel at the other, consisting of a wooden block having a brass plate on one side connected to the earth wire and joining on to the framework by means of screwing a pin through the block into a tapped hole on the machine. When it is required to reverse the motor the plug is withdrawn and reversed (see Fig. 7). There have been four fatal accidents with this type of plug within the author's knowledge.

Such arrangements have proved to be entirely unsatisfactory and have indicated the necessity for making the earth connections automatic and secure.

The danger of shock is increased on coal-cutters which are working on a fairly wet coal face.

At least one case has occurred where a man has been fatally injured when setting the cutting tools on a coal-cutter at a time when the motor has been accidentally restarted after a stoppage.

Attention is drawn to a recent experience at Clifton Colliery, Nottingham, in which two men lost their lives (see report of Mr. R. Nelson, His Majesty's Electrical Inspector of Mines, in *Electrician*, July 16, 1909).

Objects.

The author has devised and put into commission a system to reduce such risks. The object has been to provide a gate-end switch-box having automatic features which ensure cutting off the supply to the coal-cutter motor and trailing cable under any of the following fault conditions:—

1. Persistent overload (time-limit setting).
2. Short circuit between phases (time-limit setting).
3. A fault between any phase and earth (instantaneous release).
4. No-voltage, or failure of supply (instantaneous release).
5. A break or a bad contact in the earth circuit (instantaneous release).

The other considerations which have been studied in the design of the gate-end box are as follows:—

6. Suitable connections for incoming and trailing cables.
7. Joints to be made in a place where the use of a blow lamp would not be permissible.
8. The assurance of sound earth connections between the armouring of the cable and the case.
9. Earth connections automatically made on plugs at both ends of the trailing cable.
10. The system to be as simple as possible and negative in action, *i.e.*, if any part of the system is faulty it is to be impossible to make the coal-cutter motor alive.
11. No live parts to be accessible to the miner.
12. The case to be made so that there is no risk of an internal explosion permitting flame to be emitted therefrom.

13. The arrangement of the plug and sockets to be made so that it is impossible to draw out an arc in operating them. Provisions to be provided whereby a man at the coal-cutter frame can conveniently open the gate-end switch and is assured that the gate-end switch cannot be closed without his consent.

    It is to be impossible to close the main switch if either of the plugs are out of position and lying on the ground in order that it should be impossible to get a shock off the plug when in this position, the switch being made so that it is impossible to close the circuit or hold the switch in on a fault.
14. It is to be impossible to lock off the automatic gear to render it inoperative.
15. There is to be an absence of fuses. It was considered that numerous cases of shock and burns to workmen have been brought about by unskilled men replacing blown fuses with a dim light available from the safety lamp.

    Moreover, a great deal of time is wasted in replacing fuses which have blown. The majority of men working on coal-cutting machinery are paid by the number of yards or ton of mineral cut, and experience has shown that they will, rather than be delayed in any way, overfuse the machine in order to get a heavier feed on the cutter, thus overloading the motor and endangering the operation of coal-cutting.

    It was therefore considered necessary to dispense with fuses altogether and, in preference to the fuses, an automatic switch arranged in such a way that it is practically impossible for unauthorised persons to alter the setting.

Description.

The system involves the use of a trailing cable having a pilot or subsiding wire in addition to an earth conductor (Fig. 5).

The gate-end switch (Fig. 7) is controlled by a solenoid in circuit with the pilot and earth conductor, so that, if the earth circuit is not complete, current cannot pass through the solenoid, and it is impossible to close the switch.

Fig. 2 shows the arrangement for a 3-phase supply having an earthed neutral, and Fig. 1 illustrates corresponding connections when used on a direct-current supply with an earthed neutral-point obtained by the addition of an extra brush on the commutator of the generator in the power station.

Reverting again to Figs. 1 and 2, it will be seen that when the operating switch M is closed, and provided the pilot circuit E_1 and the earth conductor E are complete through the framework of the machine, then the solenoid P is energised and the main switch is closed. On releasing the handle of the control switch M the switch

springs automatically on to the contact No. 1, which puts a high-resistance solenoid in circuit and also affects a change-over by which the connection through the solenoid is taken from the outgoing side of the switch. It will be seen that the main switch cannot be held in the closed position unless current passes through the solenoid, and there will be no circuit through the solenoid unless the earth circuit is complete through E and E_1, or if the supply voltage fails. By this means the switch opens automatically under the required fault conditions enumerated above.

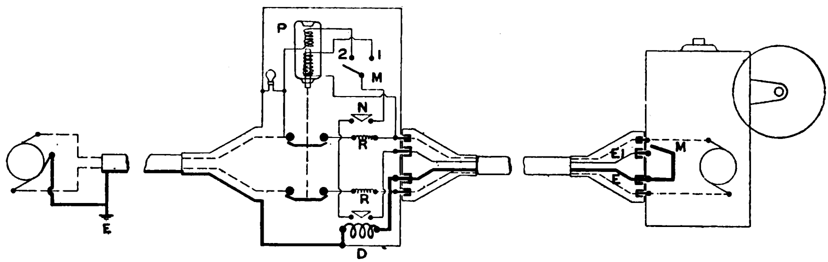


FIG. 1.

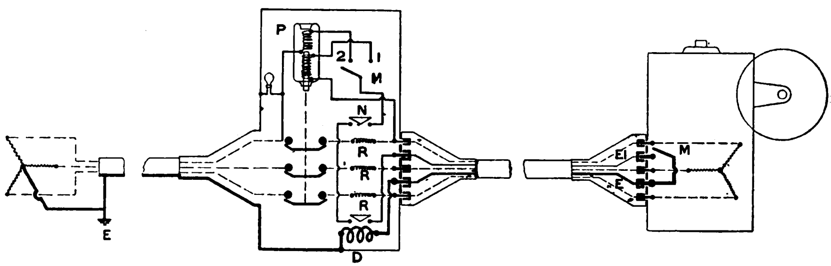


FIG. 2.

Figs. 3 and 4 show the details of the gate-end box. S is a 3-pole oil-break switch fitted with three overload release coils R, R, R, having a time-lagging device of the oil dash-pot type. A scale Y is provided for adjusting the setting of this overload arrangement.

P is the controlling solenoid and has two windings, one of which is used to give a maximum pull at the moment of closing the switch, and the other is a coil of high resistance consuming only the small amount of energy sufficient to hold up the armature when the switch is in the "on" position, but the switch is knocked out by means of simple

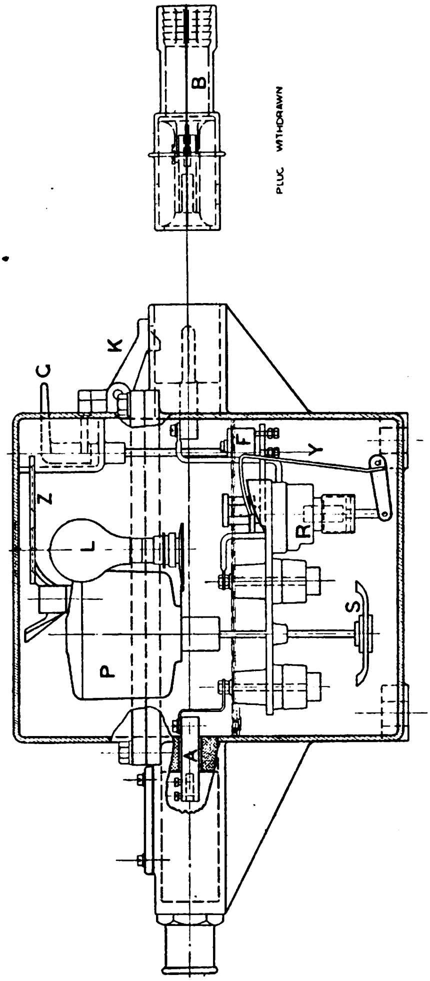


FIG. 4.

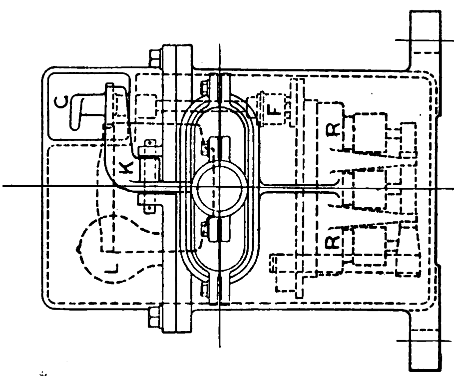
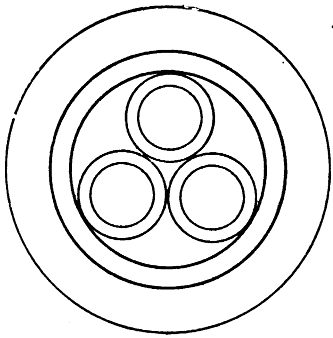


FIG. 3.

mechanism, when the weight of the armature is released by the solenoid.

F is a small control switch operated from the outside of the box at the handle G. This arrangement of control is on a free handle principle —*i.e.*, in the event of a fault occurring the main switch was bound to



Exact size of cable

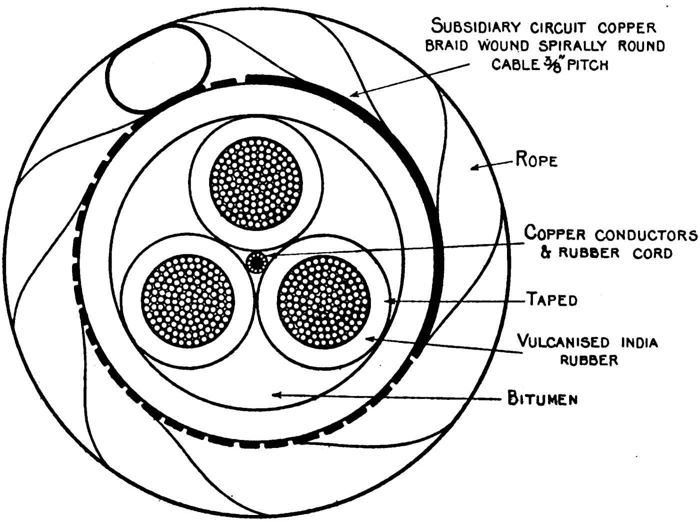


Fig. 5.

trip out even though the control switch is held by the operator's hand, or even if an attempt is made by a dauntless operator to tamper with the device. The argument has been raised against automatic gear in collieries that automatic switches can be locked out of action. It will be seen that this danger cannot exist with the method shown on the above illustrations.

L is an indicating lamp which, by the aid of a simple shutter device, shows a light through a strong glass window and gives a clear indication so that it can be seen from the outside whether the switch is "on" or "off." The lamp is connected to the incoming cable, and so, when no light is shown, it indicates that the supply is cut off from this source.

The overload release coils R and R, in operating, open the control circuit and so release the main switch. The complete mechanism is enclosed in a strong iron case. The current-breaking parts are immersed in oil. The case and lid have wide machined joints to avoid the possibility of an omission of flame. Mechanical terminals are provided throughout so that joints can be made without soldering. Those at A take the incoming cable, the insulated ends of which are situated in a box which can be run in solid with compound for the

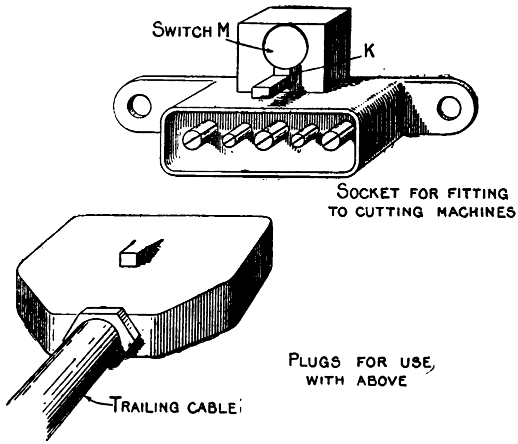


FIG. 6.

purpose of sealing the ends. Suitable glands are provided for earthing the armour thoroughly to the box. The trailing cable is attached to the plug B. The plug is enclosed in a strong cast-iron case, and it is so interlocked with the control switch that it is impossible to withdraw the plug when the main switch is closed. This interlocking is effected by a simple pawl at K, and it is obvious that it is impossible to draw out an arc in manipulating the plug for the reason that the plug cannot be withdrawn when the circuit is alive. A corresponding plug is used at the coal-cutter end of the trailing cable, and a socket is made, as shown on Fig. 6, suitable for fixing to any existing coal-cutter frame. Like the corresponding socket on the gate-end box, it carries a locking pawl K, inter-connected with a small switch by which the men working the coal-cutter can open the control circuit, and so make the trailer and the motor dead, and ensure that they cannot be made alive until the

switch is closed at the coal-cutter end. This is an important factor in the safe working of coal-cutters, and has not been provided for in any previous system. It is true that arrangements have been made which cut off the current to the motor at the coal-cutter end, but the author's system enables a supply to be cut off right back to the gate-end box, and not only disconnects the motor, but the trailing-cable as well, and at the same time prevents any one accidentally closing this circuit if the men at the coal-cutter are carrying out any work on the machine.

The plug is made reversible so that the motor can be reversed, if necessary, by simply withdrawing the plug and reinserting it the other way round.

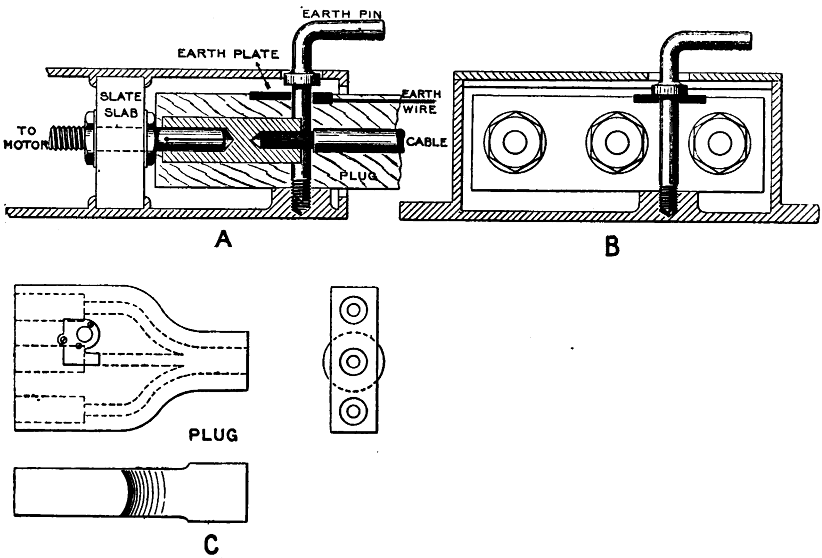


FIG. 7.

It is obvious that, if the plug is not in the socket, the control circuit is incomplete, and so it is impossible to close the main switch with the plug lying on the ground.

It may be argued that there are an excessive number of parts to maintain on the switch. Appreciating this it has been the endeavour in the design to reduce these parts to a minimum, and so completely to enclose the apparatus that nothing can be tampered with by inexperienced men in bye. In the event of any part requiring skilled attention it is a simple matter to remove the complete interior working parts from the case and, if necessary, to get the circuit going again quickly, to replace them by another set whilst the first set is taken to the pit-head, or to a convenient place where there is plenty of light and room available for proper inspection.

In the objects enumerated above, it has been mentioned that the switch was to open instantaneously in the event of a fault or leakage to earth occurring on the coal-cutter motor or on the trailing cable. This object has been attained in a very simple manner. Mr. McKie and Mr. Georgi have both proposed a system for branch feeders in which a relay is inserted in the earth conductor. The relay operates when any current passes through the earth conductor, such as would be the case in the event of a leakage. This idea, as shown by letter D as applied to the gate-end box (Figs. 1 and 2), represents the coil which is connected between the earth conductor in the trailer and the switch case. This electromagnet operates on a current well above that required through the solenoid of the main switch, in order to discriminate between the normal current in this earth circuit and the current which is there on account of a fault. It will be seen from the diagram that the electromagnet in operating opens the control circuit in a manner similar to the overload release. The distinction between the overload release and the leakage release is that the overload operates on a heavy persistent overload or fault between phases, whilst the leakage protection trips the switch instantly with a current which forms a small proportion of the normal full load.

It is suggested that the system described above may be of service on other electrical installations. It may be used with advantage to protect odd numbers of sections between main switchboards at bank and distribution centres in bye, in such cases where it is required to embody a system for remote control, and to ensure against accidents due to incomplete earth circuits. Moreover, it may be applied to portable machinery in factories, shipyards, ironworks, etc. For example, wharf-cranes and other portable apparatus where, to be strictly in accordance with Home Office regulations, and in order to avoid danger, it is essential to have efficient earth connections.

It should be said in conclusion that the system under discussion has had extended trial underground. Several times the earth wire was broken accidentally, and in every case the gate-end switch was opened and could not be closed again until a new trailing cable had been inserted.

Only one apparatus has been discussed in this paper, but it has introduced subjects which concern other apparatus also, and the author ventures to hope that it may lead to a useful general discussion on the safe application of electricity in the mines.*

Discussion.

Professor Thornton.

Professor W. M. Thornton: If all collieries had apparatus of this kind there would be no need for the debate on the question of danger in mines from electricity. The apparatus seems to have all the points that make for safety. I presume the box is explosion proof. With regard to bonding I heard of a case where the coupling was not

* The system installed is Patent No. 12452/09, Fisher. The switch-box for ditto, Patent No. 20590/08, Fisher, Reyrolle & Co., and others.

bonded across as in the apparatus, and a fatal accident occurred due to this. I think the absence of fuses is most important, as mentioned on page 666. Regarding the avoidance of twisting by using the outside sheathing described by Mr. Fisher, the only danger is that there might be a twist on the inside cable, which would be likely to fuse. Professor Thornton.

Mr. W. W. Wood: A coalcutter may make either a moderately good or a very bad connection to earth, according to the ground on which it is standing. Assuming first that the connection to earth is good, it appears that even if the earth wire E were interrupted, the switch might possibly still remain in the "on" position, current flowing through the solenoid P along the pilot wire, and back through the earth (not through the earth wire). In any case I should expect that the earth circuit, acting as a shunt across the earthing wire, would materially affect the operation of the overload device D. It is quite possible, however, for a coalcutter to have a very high contact resistance with the ground on which it stands, and this was clearly shown in the case of the Clifton colliery accident referred to on page 665 of Mr. Fisher's paper. The circumstances of this accident were briefly as follows: The earth connection was faulty owing to a mechanical defect, and the coalcutter frame became connected to one phase owing to damage to the insulation on a wire forming part of the winding of the motor. Two men were killed. One was actually standing on the machine and operating the controller, and his head is supposed to have touched the roof above, completing the circuit to earth. The other man was kneeling by the machine and touching it. The coalcutter was not insulated from earth but simply resting on metal skids on the ground, and the man received a fatal shock through the ground. The voltage of supply was 500 approximately, 25 cycles. It will be seen that under certain circumstances a coalcutter can be practically treated as insulated from earth, although it is standing on it, and under such conditions it appears as if an accident might arise through the use of Mr. Fisher's switch somewhat as follows: Assuming that two men work a coalcutter and the earth connection is broken unknown to them, the switch at once interrupts the supply, one man stays by the coalcutter and happens to be touching it, and the other man goes back to the switch to see what is the matter. He tries to start up, and in doing so he connects the coalcutter frame (assuming that the switch on the coalcutter itself is closed) to one phase through the low-resistance striking coil, *i.e.*, the solenoid. As the earth wire is broken and the machine is making bad contact to earth, the pressure from the coalcutter frame to earth will be approximately the full voltage of one phase, and a man touching it will receive a shock due to this. The current that can flow will of course be limited to the current which can pass through the solenoid, but it is quite possible that this would be sufficient to give a fatal shock if it went through a vital part. Mr. Wood.

Mr. W. G. Guns: I should like to know if it is possible to do without the high-resistance coil, as there are lamps, used for indicating, which could be put in series with one of the other coils to give a Mr. Guns.

Mr. Guns. reduced current for maintaining the armature after the solenoid has operated the switch.

Mr. Clothier. Mr. H. W. CLOTHIER: I can speak with some knowledge of the details of Mr. Fisher's system, as I and my colleagues have spent many interesting hours in the study of the design. It is necessary for manufacturers to have the experience and guidance of users to enable them to produce something to comply with the necessary requirements for safety. Some figures I have of the accidents in mines show that there is an absolute necessity for improvement in the application of electricity in mining, and that good work can be done by a scheme such as Mr. Fisher shows us. It is surprising that electricity seems more dangerous below ground than above, but this is probably due to the clamminess in the air in mines, making the surface resistance a great deal lower. The chief causes of explosions are arcing and sparking, and the only way to avoid these is to have an absolutely instant release to cut off the current directly a fault occurs. To avoid shock it should be impossible for persons to come in contact with the line conductor, and the very complete enclosure of Mr. Fisher's device ensures this.

Mr. Fisher. Mr. FISHER (*in reply*): The question of shock which Mr. Wood raises has never taken place in practice, although both wires have been repeatedly broken. This point was raised some time ago and has been got rid of by the insertion of a high resistance, or a voltage reducer, so that it is now impossible for a man to receive a dangerous shock.

AN INVESTIGATION AS TO THE MOST ECONOMICAL VACUUM IN ELECTRIC POWER STATIONS EMPLOYING STEAM TURBINES AND COOLING TOWERS.

By R. M. NEILSON.

(*Paper received from the* GLASGOW LOCAL SECTION, *October* 27, 1909, *and read at Glasgow on January* 11, 1910.)

Since the extensive employment of steam turbines in electric power stations the questions of vacuum and condensing plant have received more attention than heretofore. The advantage which turbines derive from high vacuum is well known, and it is a relatively easy matter to determine what is the best vacuum at which to run a station or a unit with existing plant. It is, however, a more complicated problem to determine what is the most economical vacuum for which to design a new station or extension of a station. To solve this problem it is necessary to decide what items in the plant are appreciably affected in first cost by the vacuum, and what items of annual expenditure are appreciably influenced by it.

In the present investigation the author has decided that the only items in the initial cost of the power station which are affected by vacuum to an extent worth taking numerically into consideration are the boiler plant and the condensing plant: the plant included under these headings will be specified later on.

The author has also decided to include in the annual charges which are affected by vacuum the coal only, in addition to the interest, depreciation, maintenance, etc., on the boiler and condensing plant. The other numerous items which make up the total cost of the generation and delivery of a unit of electricity are considered to be affected by the vacuum to an extent not worth taking into account in the calculations and curves, but some remarks are made upon them in a later part of the paper.

A station has been considered in which the main units consist of three steam turbo-alternators, each rated at 3,000 k.w., but capable of carrying a considerable overload, although working most economically at or near their rated capacity. Water-tube boilers are assumed, and surface condensers and electrically driven condenser auxiliaries. The condensing water is assumed to be cooled in natural draught cooling towers and repeatedly used, the small percentage lost in each cycle being continually made good.

Considering in the first place a plant load factor of 10 per cent.,* Fig. 1, curve B, shows how the vacuum affects the cost for interest, depreciation, repairs, maintenance, rates, taxes, and insurance on the boiler plant. The cost itself is not given, but only the difference between the cost at any vacuum and that at 27-in. vacuum.† As the vacuum provided for in the design of the station rises from 25 in., the estimated steam consumption per kilowatt-hour of the turbo-generators can be reduced, and hence the necessary boiler capacity falls; but, at high vacuum, the power consumption of the condenser auxiliaries rises, and at an increasing rate, so as to ultimately overweigh the increasing

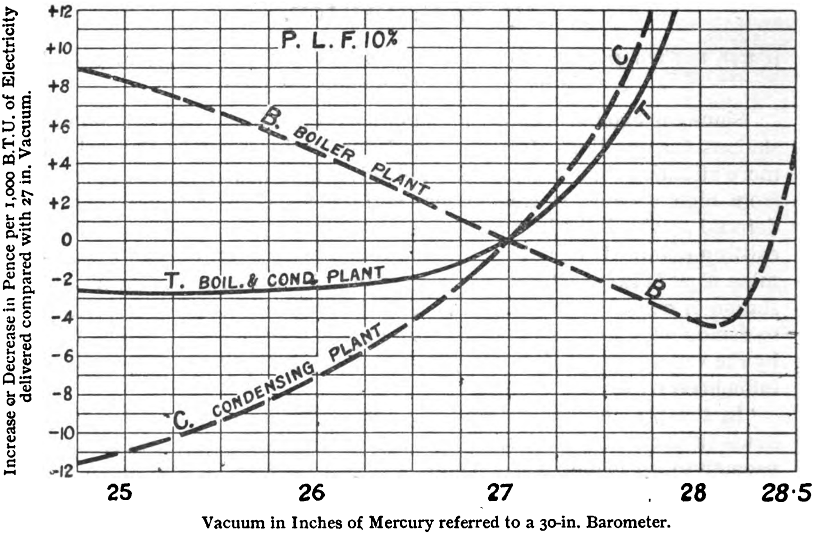


FIG. 1.—Effect of Vacuum as regards Interest, Depreciation, Maintenance, Rates, Taxes, and Insurance on Boiler and Condensing Plant. Plant Load Factor, 10 per Cent.

economy of the turbo-generator; and the steam consumption per B.T.U.‡ of electricity delivered § from the station rises, so causing an increase in the initial cost of the boiler plant. The boiler-plant curve is, therefore, as shown in curve B in Fig. 1.

Curve C, Fig. 1, is of the same nature as B, but refers to the con-

* By this is meant that the total B.T.U. of electricity annually delivered from the station—*i e.*, the gross output of the generators minus the amount consumed in the working of the station—is 10 per cent. of 9,000 × 24 × 365.

† The vacua mentioned in this paper always refer to a 30-in. barometer.

‡ B.T.U. = Board of Trade Unit. B.Th.U. = British Thermal Unit.

§ By electricity delivered is meant the net output after deducting the power consumed in running the station.

densing plant. This curve rises at an increasing rate as the vacuum provided for goes up.

Curve T, in Fig. 1, is obtained by taking the algebraic sum of the ordinates in curves B and C, and shows what would be the most economical vacuum for which to design the station if there were no charge for coal.

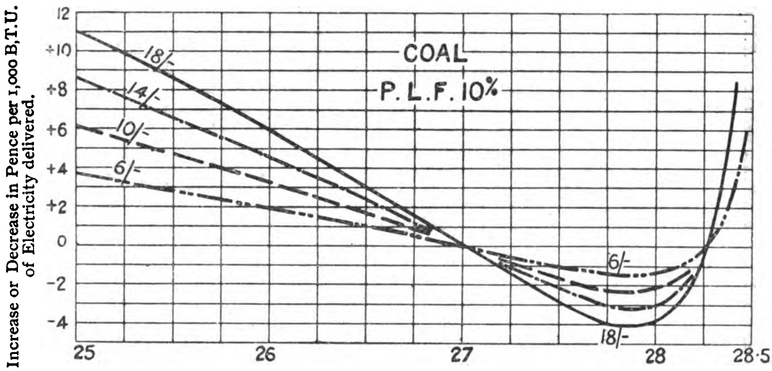


FIG. 2.—Effect of Vacuum as regards Cost of Coal. Plant Load Factor, 10 per cent. The Cost of the Coal in Shillings per Ton of 2,240 lbs., and of a Thermal Value of 13,000 B.Th.U. per lb. is indicated on the Curves.

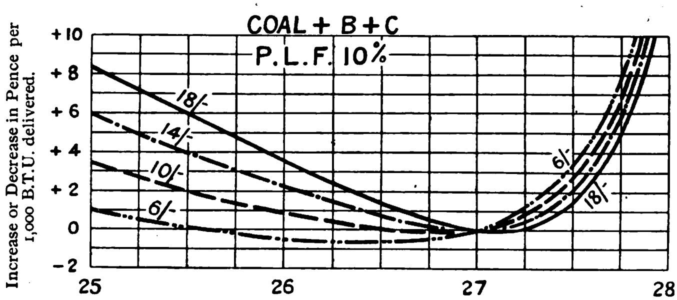


FIG. 3.—Showing the most Economical Vacuum for a Plant Load Factor of 10 per Cent.

Fig. 2 expresses the cost of coal per B.T.U. of electricity delivered, according to the price of coal per ton. The numerals on the curves represent the cost of the coal in shillings per ton Remarks are made later as to the thermal value of the coal.

By combining Fig. 1 with Fig. 2 we obtain Fig. 3, which shows the aggregate variation in the items which vary with the vacuum, and the

most economical vacuum is seen to be at about 26¼ in. for coal at 6s. a ton, and at between 27 in. and 27¼ in. for coal at 18s., intermediate prices of coal giving intermediate best vacua.

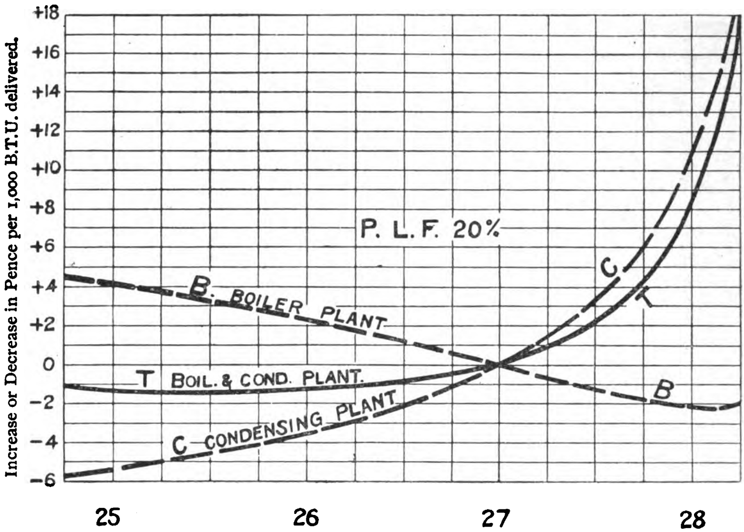


FIG. 4.—Effect of Vacuum as regards Interest, Depreciation, Repairs, Maintenance, Rates, Taxes, and Insurance on Boiler and Condensing Plant. Plant Load Factor, 20 per Cent.

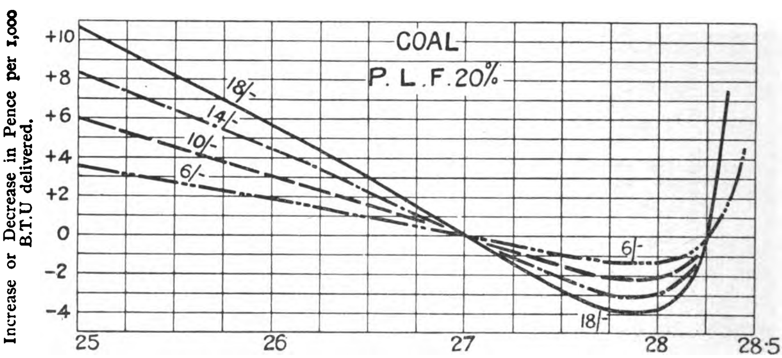


FIG. 5.—Effect of Vacuum as regards Cost of Coal. Plant Load Factor, 20 per cent. The Cost of Coal in Shillings per Ton of 2,240 lbs. and of a Thermal value of 13,000 B.Th.U. per lb. is indicated on the Curves.

Figs. 4 to 6 are of the same nature as Figs. 1 to 3, but refer to a plant load factor of 20 per cent. The relative importance of low first cost. is much less in this case than in the previous, a fact which, of

course, will be recognised, and can be seen by comparing curves B and C in Fig. 1 with the corresponding curves in Fig. 4. The coal, therefore, controls the final result to a greater extent in this case than in the other, and the best vacuum is seen to vary from about 26¾ in. with coal at 6s. to between 27¼ in. and 27½ in. with coal at 18s.

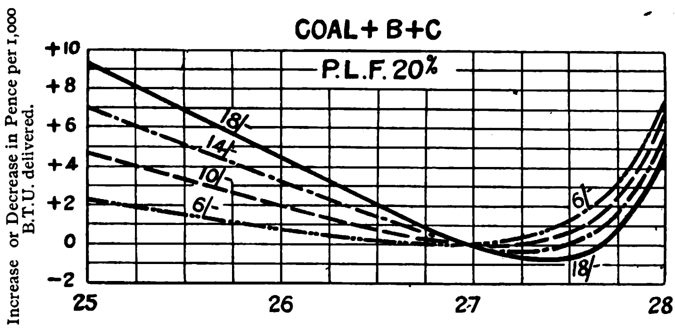


FIG. 6.—Showing the most Economical Vacuum for a Plant Load Factor of 20 per Cent.

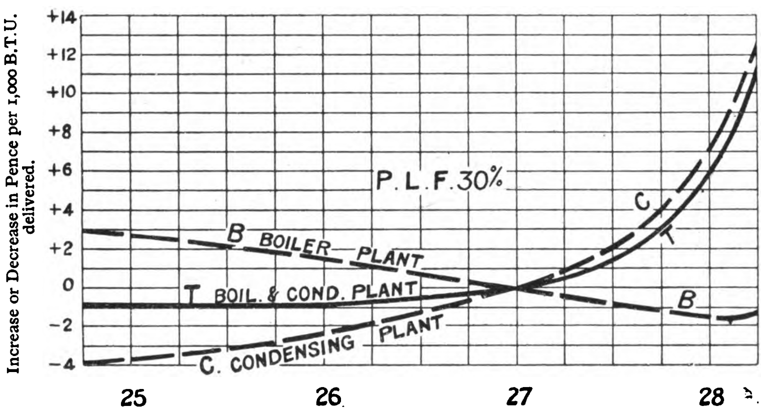


FIG. 7.—Effect of Vacuum as regards Interest, Depreciation, Repairs, Maintenance, Rates, Taxes, and Insurance on Boiler and Condensing Plant. Plant Load Factor, 30 per Cent.

Figs. 7 to 9 refer to a plant load factor of 30 per cent., and it will be seen that the final result with 30 per cent. plant load factor is only slightly different from that with 20 per cent. The difference between 30 and 40 per cent. would be still less; in fact, each successive increase of 10 per cent. in plant load factor makes a continually less difference in the

most economical vacuum. The differences are, in fact, approximately proportional to the differences between $\frac{100}{10}$, $\frac{100}{20}$, $\frac{100}{30}$, $\frac{100}{40}$, etc., so that it seems unnecessary to draw curves for any plant load factor above 30 per cent. If, however, the best vacuum should be required for a plant load factor of, say, 5 per cent., new curves should be prepared, as the difference between 5 and 10 per cent. is about twice as great as that between 10 and 20 per cent. The best vacuum for a plant load factor of 5 per cent. has not been worked out by the author on the same basis as for the other plant load factors, but it would lie between 25½ in. and 27 in., according to the price of coal.* It may be said that, unless in very exceptional cases, the most economical vacuum for any plant load factor and any price of coal will never fall

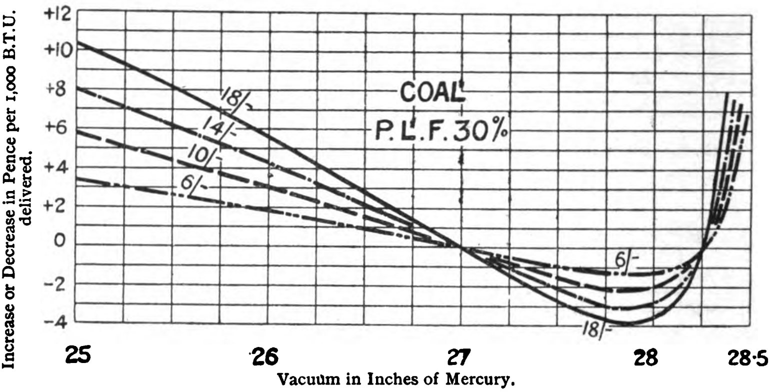


FIG. 8.—Effect of Vacuum as regards Cost of Coal. Plant Load Factor, 30 per cent. The cost of the Coal in Shillings per Ton of 2,240 lbs. and of a Thermal Value of 13,000 B.Th.U. per lb. is indicated on the Curves.

below 25 in., and never rise as high as 27¾ in. It must be remembered that this applies only to stations taking their condensing water from cooling towers.

It would be possible to draw curves with the plant load factors as abscissæ and the most economical vacua as ordinates, but the author has refrained from putting forward such curves, as he believes that Figs. 3, 6, and 9 are preferable, as these indicate the best vacua with sufficient exactitude, while they are also most useful in showing how

* If it is desired to obtain with the minimum of labour the greatest aggregate of useful results over the whole range of plant load factors, the latter should not be chosen as has been done in the present investigation, but should be more evenly spaced as regards their reciprocals. Suitable series of plant load factors would be 7½, 12½, and 35 per cent., or 6, 10, 20, and 60 per cent. In the present investigation the plant load factors were chosen with a view to illustrate the method of investigation as well as to give results under conditions usual in practice, and it was desired to show the small difference between 20 and 30 per cent.

far the best vacuum can be departed from without substantial disadvantage. For example, referring to Fig. 6, it is sufficient to know that with coal at 14s. per ton the most economical vacuum is in the neighbourhood of 27¼ in. It would be absurd to try to locate the best vacuum to a hundredth of an inch when the greatest difference between 27 and 27½ in. amounts to less than a halfpenny per 1,000 B.T.U. delivered.

As regards the method adopted by the author to obtain data for his curves, his plan has involved assuming an initial cost for boiler plant and condensing plant, in both cases for 27-in. vacuum. He has then made an assumption as to the variation in the steam consumption of the turbo-generators with varying vacuum, and thus, allowing for the varying power consumption of the condenser auxiliaries, and the varying hot-well temperature, he has obtained the increase or decrease in the boiler-plant cost consistent with the varying aggregate of B.Th.U.

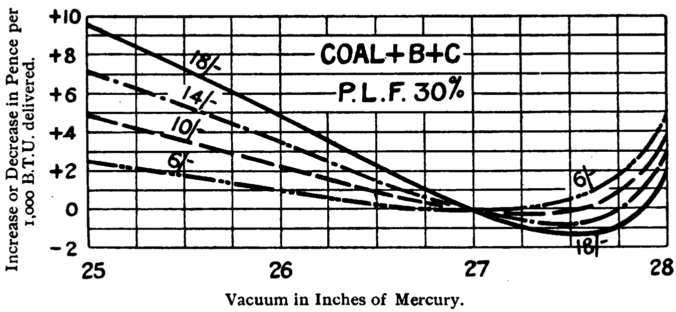


FIG. 9.—Showing the most Economical Vacuum for a Plant Load Factor of 30 per Cent.

required to be given to the water per B.T.U. of electricity delivered. The percentage variation in the cost of the condensing plant with varying vacuum has also been worked out.

The depreciation, repairs, and maintenance on the boiler plant have been taken at 10 per cent., and the same figure has been assumed as a mean on the condensing plant, including the cooling tower. Seven per cent. additional has been added in each case for interest, rates, etc., so that the total annual charge on boiler and condensing plant is 17 per cent. of the initial cost, which includes cost of erection.

Different coal consumptions per B.T.U. delivered have been assumed for the three plant load factors, in each case for 27 in. vacuum, and the variation in the coal consumption with variation in vacuum has been worked out. Then, taking four different prices for coal, the difference in cost of coal per 1,000 B.T.U. of electricity delivered has been calculated. The coal has been reckoned as of a

uniform calorific value of 13,000 B.Th.U., so that for coal of a greater or less calorific value a correction must be made.*

The prices of boiler and condensing plant vary to a certain extent, but it can be proved by trial that an alteration of even 10 per cent. in the prices assumed will be hardly noticeable in the final curves (Figs. 3, 6, and 9); only the variation in cost—not the total cost—has been used in preparing the curves.

An opportunity for a slight difference between the best vacuum as indicated by the curves and the actual best vacuum in some particular cases has reference to the variation in the steam consumption of the turbo-generators with variation in vacuum. The author's curves are based on what is believed to be an average variation of steam consumption with vacuum; but the variation is not the same in all cases; it depends on (1) the type of turbine employed; (2) the connection between the turbine and the condenser; (3) the provision made for utilising high vacuum in the design of the turbine.

The three points are to a certain extent mutually involved, and much could be written on the subject; but this is outside the scope of the present paper. Suffice it to say that the type, design, and arrangement of turbines do not so greatly influence the effect of vacuum on steam consumption below 27½ in. as above this figure, so that the points of maximum sag in the curves in Figs. 3, 6, and 9 are not so much affected as if these points had occurred more to the right.

It has already been said that the only items of cost taken numerically into consideration in the present investigation are coal, boiler plant, and condensing plant. The method of ascertaining the effect of vacuum on the two former is indicated by Tables I., II., and III. The effect of vacuum on the cost of condensing plant is a much more complicated matter which cannot be adequately dealt with in this paper; a summary only is given in Table IV.

The boiler plant includes boilers, superheaters, feed-water heaters, feed pumps, water pipes, steam piping, and appliances for dealing with the coal and ash; and the cost of these, including erection, has been taken as £3·5 per kilowatt for 27-in. vacuum.

The condensing plant includes surface condensers, air pumps, circulating water pumps, and natural-draught cooling towers, and all circulating water piping. The aggregate cost of these items has been taken as £1·4 per kilowatt for 27-in. vacuum.

Table V. gives the annual charge for depreciation, repairs, etc., on the boiler and condensing plant; and in Tables VI. and VII. the data obtained from Tables I., IV. and V. are made use of to obtain the increase or decrease in cost per 1,000 B.T.U. delivered for boiler and condensing plant. In Tables VIII., IX., and X. the data from Tables I., II., and III. are employed to obtain the increase or decrease in cost of coal per 1,000 B.T.U. delivered.

* It is usually sufficient in this matter to take the real value of the coal to the power station as equivalent to the thermal value, so that coal of, say, 11,700 B.Th.U. at, say, 9s. a ton, may be taken as the equivalent of coal of 13,000 B.Th.U. at 10s. a ton

Coal and per Cent.

(The last obtained.)

1	Vacuum referred to 30-i barometer ...		28·5	
2	Increase or decrease steam consumption turbo-generator com pared with 27-i vacuum	2	− 8·0	assumed
3	Steam consumption p unit generated at fu load, the consumpti at 27-in. vacuum bei taken as basis ...	7	16·65	I. 2
4	Steam consumption p unit generated, me of varying loads, t consumption at 27-i vacuum being taken basis	756	18·4	assumed
5	Electricity generated p lb. of steam at full lo	92	0·06006	I. 3
6	Electricity generated p lb. of steam, mean varying loads ...	30	0·05435	I. 4
7	Electricity taken by co densers auxiliaries p lb. of steam used turbine at full load	40	0·00639	IV. 9
8	Electricity taken by co densers auxiliaries p lb. of steam used turbine—mean of var ing loads ...	36	0·00896	IV. 10
9	Net electricity delivered per lb. of steam — Full lo	52	0·05367	I. 5 and 7
10	Net electricity delivered per lb. of steam — Mean varyi	94	0·04539	I. 6 and 8
11	Steam per B.T.U. of elec- tricity de- livered ... — Full lo	69	18·64	I. 9
12	Steam per B.T.U. of elec- tricity de- livered ... — Mean varyi loads	02	22·045	I. 10
13	Steam per hour at full lo	70	55,920	I. 11
14	Assumed hot-well te perature	$8\frac{1}{2}$	85	assumed
15	Gain or loss of heat co pared with 27-in. vacu	$\frac{1}{2}$	−18	I. 14
16	Coal per B.T.U. delive at $7\frac{1}{2}$ lbs. of steam lb. of coal, allowing variation in hot-w temperature ...	716	2·997	I. 12 and 15, and assumed
17	Increase or decrease coal per B.T.U. livered compared w	173	+0·2639	I. 10
18	27-in. vacuum ...	33	+9·650	I. 16
19	Increase or decrease steam required per h at full load compa	00	+750	I. 13
20	with 27-in. vacuum	1	+1·36	I. 13
21	Effect of hot-well te perature on initial c of boiler plant as a p centage of the cost 27-in. vacuum ...	243	+1·554	I. 15
22	Net increase or decre in cost of boiler pl compared with 27- vacuum	567	+2·904	I. 20 and 21

Table II.

Coal.—Plant Load Factor=10 per Cent.

(The last column gives a reference to the table and line from which the figures have been obtained.)

1	Vacuum referred to 30-in. barometer	Inches. 25	Inches. 26	Inches. 27	Inches. 27·5	Inches. 28	Inches. 28·2	Inches. 28·5	
2	Coal per B.T.U. delivered, allowing for variation in hot-well temperature *	Lbs. 2·951	Lbs. 2·8973	Lbs. 2·8358	Lbs. 2·806	Lbs. 2·7958	Lbs. 2·818	Lbs. 3·110	see foot-note
3	Increase or decrease in coal per B.T.U. delivered compared with 27-in. vacuum	+0·115	+0·0615	0	−0·0298	−9·0402	−0·0179	+0·2738	II. 2
4		Per Cent. +4·06	Per Cent. +2·17	Per Cent. 0	Per Cent. −1·05	Per Cent. −1·417	Per Cent. −0·633	Per Cent. +9·650	II. 2

* This coal consumption is taken from Table I. with a 3·75 per cent. increase due to the less mean load on the turbine owing to the lower plant load factor.

Table III.

Coal.—Plant Load Factor=30 per Cent.

(The last column gives a reference to the table and line from which the figures have been obtained.)

1	Vacuum referred to 30-in. barometer	Inches. 25	Inches. 26	Inches. 27	Inches. 27·5	Inches. 28	Inches. 28·2	Inches. 28·5	
2	Coal per B.T.U. delivered, allowing for variation in hot-well temperature *	Lbs. 2·773	Lbs. 2·723	Lbs. 2·665	Lbs. 2·637	Lbs. 2·6275	Lbs. 2·648	Lbs. 2·922	see foot-note
3	Increase or decrease in coal per B.T.U. delivered compared with 27-in. vacuum	+0·1082	+0·0578	0	−0·0280	−0·0377	−0·0169	+0·2572	III. 2
4		Per Cent. +4·06	Per Cent. +2·17	Per Cent. 0	Per Cent. −1·05	Per Cent. −1·417	Per Cent. −0·633	Per Cent. +9·65	III. 2

* This coal consumption is taken from Table I. with a 2·5 per cent. decrease due to the greater mean load on the turbine owing to the greater plant load factor.

Table IV.

Condensing Plant for Each Turbine.

(The last column gives a reference to the table and line from which the figures have been obtained.)

1	Vacuum inches of mercury	25	26	27	27·5	28	28·2	28·5	
2	Cost of air pump and motor	£ 455	£ 518	£ 605	£ 673	£ 758	£ 802	£ 947	Calculations not given
3	Cost of circular pump and motor	222	243	299	362	539	704	1,670	
4	Cost of surface condenser	1,192	1,330	1,521	1,653	1,910	2,113	3,051	
5	Cost of cooling tower ...	1,598	1,619	1,741	1,887	2,356	2,712	5,048	
6	Total cost	3,467	3,710	4,166	4,575	5,563	6,331	10,716	IV. 2-5
7	Increase or decrease in cost compared with 27-in. vacuum	−699	−456	0	+409	+1,397	+2,165	+6,550	IV. 6
8		Per Cent. −16·79	Per Cent. −1·095	Per Cent. 0	Per Cent +9·84	Per Cent. +33·53	Per Cent. +52·05	Per Cent. +157·3	V. 6
9	Electricity taken by condenser auxiliaries per lb. of steam used by turbine at full load ...	B.T.U. 0·00051	B.T.U. 0·00063	B.T.U. 0·00087	B.T.U. 0·00113	B.T.U. 0·00178	B.T.U. 0·00240	B.T.U. 0·00639	Calculations not given
10	Electricity taken by condenser auxiliaries per lb. of steam used by turbine —mean of varying loads	0·00071	0·00088	0·00122	0·00158	0·00249	0·00336	0·00896	

Table V.

Cost of Boilers and Condensing Plant per B.T.U. of Electricity delivered. Vacuum = 27 in.

Plant load factor of 10 per cent. corresponds to 876 B.T.U. per year per kilowatt of rated capacity.

Plant load factor of 20 per cent. corresponds to 1,752 B.T.U. per year per kilowatt of rated capacity.

Plant load factor of 30 per cent. corresponds to 2,628 B.T.U. per year per kilowatt of rated capacity.

	Initial Cost per Kilowatt of Rated Capacity	Depreciation, Repairs, and Maintenance.	Depreciation, Repairs, and Maintenance +7 per Cent. for Interest, Rates, Taxes, and Insurance.			
				Per B.T.U. of Electricity Delivered.		
	£	Per Cent. of Capital Outlay.	Per Cent. of Capital Outlay.	With Plant Load Factor of 10 per Cent.	With Plant Load Factor of 20 per Cent.	With Plant Load Factor of 30 per Cent.
				d.	d.	d.
Boiler plant	3·5 (ass'm'd)	10 (assumed)	17	$\frac{0·17 \times 3·5 \times 240}{876}$ =0·163	$\frac{0·17 \times 3·5 \times 240}{1752}$ =0·0815	$\frac{0·17 \times 3·5 \times 240}{2628}$ =0·0544
Condensing plant	1·4 (from IV. 6)	10 (assumed mean)	17	$\frac{0·17 \times 1·4 \times 240}{876}$ =0·0652	$\frac{0·17 \times 1·4 \times 240}{1752}$ =0·0326	$\frac{0·17 \times 1·4 \times 240}{2628}$ =0·02174

Table VI.

Boiler Plant.—*Increase or Decrease in Annual Charge per 1,000 B.T.U. delivered for Depreciation, Repairs, Maintenance, Interest, Rates, Taxes, and Insurance, compared with 27-in. Vacuum.*

(*The last column gives a reference to the table and line from which the figures have been obtained.*)

1	Vacuum, inches of mercury ...		25	26	27	27·5	28	28·2	28·5	
2	Percentage increase or decrease in initial cost compared with 27-in. vacuum		+5·076	+2·867	0	−1·3354	−2·6160	−2·567	+2·904	I. 22
			d.	d.	d.	d.	d.	d.	d.	
3	Increase or decrease in annual charge per 1,000 B.T.U. delivered compared with 27-in. vacuum	P.L.F. 10 %	+8·283	+4·680	0	−2·1789	−4·2690	−4·188	+4·740	V. and VI. 2*
4		P.L.F. 20 %	+4·142	+2·340	0	−1·0894	−2·1345	−2·094	+2·370	V. and VI. 2
5		P.L.F. 30 %	+2·762	+1·560	0	−0·7263	−1·4230	−1·396	+1·580	V. and VI. 2

* For example, the 8·283 in column 3, line 3 above, is obtained by multiplying the 5·076 immediately above it by the 0·163 in Table V.

It may be advisable to refer to a few items of cost which are affected by vacuum besides the boiler and condensing plant and the coal. The oil consumption should be greater with high vacuum owing to the greater size of the condenser auxiliaries. The annual amount of make-up condensing water required to balance the continual loss

TABLE VII.

CONDENSING PLANT.—*Increase or Decrease in Annual Charge per 1,000 B.T.U. delivered for Depreciation, Repairs, Maintenance, Interest, Rates, Taxes, and Insurance, compared with 27-in. Vacuum.*

(*The last column gives a reference to the table and line from which the figures have been obtained.*)

1	Vacuum, inches of mercury ...		25	26	27	27·5	28	28·2	28·5	
2	Percentage increase or decrease in initial cost compared with 27 in. vacuum		−16·790	−10·950	0	+9·84	+33·53	+52·05	+157·3	IV. 8
			d.	d.	d.	d.	d.	d.	d.	
3	Increase or decrease in annual charge per 1,000 B.T.U. delivered compared with 27-in. vacuum	P.L.F. 10 %	−10·950	− 7·146	0	+6·42	+21·86	+33·96	+102·6	V. and VII. 2
4		P.L.F. 20 %	− 5·475	− 3·572	0	+3·21	+10·93	+16·98	+ 51·3	V. and VII. 2
5		P.L.F. 30 %	− 3·650	− 2·382	0	+2·14	+ 7·29	+11·32	+ 34·2	V. and VII. 2

TABLE VIII.

Increase or Decrease in Cost of Coal per 1,000 B.T.U. of Electricity delivered compared with 27-in. Vacuum. Plant Load Factor, 10 per Cent.

(*The last column gives a reference to the table and line from which the figures have been obtained.*)

1	Vacuum, inches of mercury		25	26	27	27·5	28	28·2	28·5	
2	Increase or decrease in coal per B.T.U. delivered compared with 27-in. vacuum ...		lbs. + 0·115	lbs. +0·0615	lbs. 0	lbs. −0·0298	lbs. −0·0402	lbs. −0·0179	lbs. + 0·2738	II. 3
3	Increase or decrease in cost of coal per 1,000 B.T.U. delivered compared with 27-in. vacuum ...	with coal at 6s. per ton	d. + 3·696	d. +1·977	d. 0	d. −0·958	d. −1·292	d. −0·575	d. + 8·800	VIII. 2
4		with coal at 10s. per ton	+ 6·160	+3·295	0	−1·596	−2·153	−0·925	+14·666	VIII. 2
5		with coal at 14s. per ton	+ 8·624	+4·613	0	−2·235	−3·014	−1·261	+20·532	VIII. 2
6		with coal at 18s. per ton	+11·088	+5·931	0	−2·873	−3·876	−1·726	+26·400	VIII. 2

through evaporation and leakage, and for periodic discharge and renewal of the water will be affected by the amount of water passed through the cooling tower per hour—which is greater the higher the vacuum—but will also be affected by the condensing water discharge temperature—which is lower the higher the vacuum—these effects will partly counterbalance each other.

No allowance has been made for variation in the area of ground required, or in the cost of the buildings with varying vacuum. The higher the vacuum, the greater the aggregate size of the cooling towers,

Table IX.

Increase or Decrease in Cost of Coal per 1,000 B.T.U. of Electricity delivered compared with 27-in. Vacuum. Plant Load Factor, 20 per Cent.

(The last column gives a reference to the table and line from which the figures have been obtained.)

		25	26	27	27·5	28	28·2	28·5	
1	Vacuum, inches of mercury	25	26	27	27·5	28	28·2	28·5	
2	Increase or decrease in coal per B.T.U. delivered compared with 27-in. vacuum ...	lbs. + 0·111	lbs. +0·0593	lbs. 0	lbs. −0·0287	lbs. −0·0387	lbs. −0·0173	lbs. + 0·2639	I. 17
3	Increase or decrease in cost of coal per 1,000 B.T.U. delivered compared with 27-in. vacuum ... with coal at 6s. per ton	d. + 3·567	d. +1·907	d. 0	d. −0·922	d. −1·245	d. −0·556	d. + 8·48	IX. 2
4	with coal at 10s. per ton	+ 5·946	+3·179	0	−1·538	−2·075	−0·927	+14·13	IX. 2
5	with coal at 14s. per ton	+ 8·325	+4·450	0	−2·153	−2·905	−1·298	+19·78	IX. 2
6	with coal at 18s. per ton	+10·703	+5·722	0	−2·768	−3·735	−1·669	+25·43	IX. 2

Table X.

Increase or Decrease in Cost of Coal per 1,000 B.T.U. of Electricity delivered compared with 27-in. Vacuum. Plant Load Factor, 30 per Cent.

(The last column gives a reference to the table and line from which the figures have been obtained.)

		25	26	27	27·5	28	28·2	28·5	
1	Vacuum, inches of mercury	25	26	27	27·5	28	28·2	28·5	
2	Increase or decrease in coal per B.T.U. delivered compared with 27-in. vacuum ...	lbs. + 0·1082	lbs. +0·0578	lbs. 0	lbs. −0·028	lbs. −0·0377	lbs. −0·0169	lbs. + 0·2572	III. 3
3	Increase or decrease in cost of coal per 1,000 B.T.U. delivered compared with 27-in. vacuum ... with coal at 6s. per ton	d. + 3·479	d. +1·858	d. 0	d. −0·900	d. −1·212	d. −0·543	d. + 8·266	X. 2
4	with coal at 10s. per ton	+ 5·798	+3·097	0	−1·500	−2·020	−0·905	+13·777	X. 2
5	with coal at 14s. per ton	+ 8·117	+4·336	0	−2·100	−2·828	−1·267	+19·288	X. 2
6	with coal at 18s. per ton	+10·437	+5·574	0	−2·700	−3·636	−1·629	+24·799	X. 2

and therefore the greater the ground area required by them. On the other hand, high vacuum slightly reduces the ground area of the boiler house and also reduces the cost of the house. It is thought that the allowances which have been made for boiler plant, condensing plant, and coal cover nearly all that is required to be taken into account, the

other variable items, where they do not balance each other, being negligible.

The present investigation is based, as already mentioned, on a station containing three turbo-generators each of 3,000 k.w., but a considerable variation could, the author considers, be made in the aggregate power of the station and in the number of units installed without greatly affecting the locality of the most economical vacuum for the different plant load factors and prices of coal. The results may, however, be considerably different for stations not dependent on cooling towers, but obtaining cold condensing water from a river, lake, canal, or from the sea.

The author hopes that this paper will be of some use—not only as showing by the curves the most economical vacuum under the conditions assumed—but as indicating a basis for further investigations as to the best vacuum under other conditions; and it is to be hoped that the discussion will bring out any weak points of the author's treatment of the subject so that any one desiring to make a similar but modified investigation may be enabled to do so to best advantage.

In conclusion, the author desires to record his thanks to friends who have kindly aided him in his investigations.

DISCUSSION.

Mr. J. A. ROBERTSON: A few years ago we only considered whether a station should be condensing or non-condensing; now every one is agreed on the necessity for condensing plant, the only question is at what vacuum the plant should be worked. The paper clearly shows that a limit is reached in every plant where the economy of higher vacuum is counterbalanced by additional capital charges and the extra power absorbed in air and circulating water pumps. If the author's results are based on actual working, the conditions must be exceptionally bad, otherwise he would not have placed the economical limit of vacuum as low as 27 in. Even with expensive cooling towers very few engineers would be content to work their turbines at 27 in. with the barometer at 30 in. I have looked through the paper for an explanation, and I think that Mr. Neilson is wrong in the amount which he allows in his calculation for repairs, maintenance, depreciation, etc. The figure of 17 per cent. is quite out of the question for central station work, and in practice 7 or 8 per cent. is the actual amount allowed. If the curves are corrected to correspond with actual practice the economical limit is raised from 27 in. to 27·8, or thereabouts. Again, in Table IV. it is assumed that a plant capable of producing 28½ in. will cost three times as much as a plant producing half an inch less. On a recent occasion when specifying condenser plant to produce 28 in. vacuum for a turbo set, two of the condenser makers offered to guarantee an additional ½ in. of vacuum with an increase in capital cost for condenser and air pumps of only 15 per cent. Even with expensive cooling towers I can hardly accept Mr. Robertson.

Mr. Robertson.

the increase of 200 per cent. as representing the normal practice, and there are turbine stations in daily operation at 28½ in. or even 29 in. vacuum where the condensing plant has certainly not cost the enormous sum which Mr. Neilson arrives at. I am afraid that an error has been made in the paper regarding load factors. The "plant load factor" referred to in the paper is really the "station load factor." This is most important, because it alters the results if the actual plant load factor is used in these calculations. In calculating how much I can afford in capital cost to obtain high vacuum for a turbine set, I shall not be concerned about the capacity or the output of the other generating sets in the station, but only about the conditions under which that particular set is run, and if I can run it at 80 per cent. load factor (quite an attainable figure), I shall adjust the expenditure for that condition, quite irrespective of the station load factor—viz., the ratio of total output to capacity—which may be as low as 20 per cent. In a certain station with eleven generating sets no less than 80 per cent. of the total output is being generated by one large turbo set; it is obvious that the capacity of the whole station has no bearing on economical vacuum for this particular set. Mr. Neilson might tell us if he has made allowance for the increased efficiency of his turbine due to the higher vacuum when plotting these curves. We were informed by Mr. Parsons some time ago that every additional inch of vacuum above 25 in. meant 4 per cent. decrease in steam consumption, and recent practice shows this to be under rather than over the actual fact. The author might also state whether he assumes reciprocating air pumps to be employed, and what would be the difference in the economical limit if a Parsons augmentor, which is said to be equivalent to air pumps of four times the volumetric capacity, were used. Much is also being done by the use of separate water and air pumps, and it is quite conceivable that under these circumstances the results in the paper might be materially altered. I suppose that standardisation of condensing plant is a long way off, but Mr. Neilson's paper at least indicates how the question may be approached from the station engineers' point of view, and shows us how to place the various factors of efficiency, capital cost, fuel costs, and load factor.

Mr. Black.

Mr. G. L. BLACK: It seems to me that what the author calls the plant load factor is really the annual load factor, which might be anything from 10 to 20 per cent. So far as I have been able to gather, he does not give the basis on which the curves have been drawn, and it would be interesting to know what this is. The principal question was to get boilers in to supply sufficient steam, which is a common difficulty in the older stations, because the boiler house tends to run away from the engine. In consequence of that, what we have aimed at has been the highest possible vacuum. A point of great interest with reference to the most economical kind of power in the condensing plant is that with any load less than full load there is not a corresponding out load from the turbine.

Mr. S. A. SIMON: At present the whole question of cooling plant is on a very unsatisfactory basis, as it is very difficult to get proper guarantees for the performance of the cooling towers. A cooling tower is usually guaranteed to cool to a certain temperature a given quantity of cooling water for a given quantity of steam, the air being at a given temperature and degree of humidity. These or even approximate conditions may occur so seldom that it might be necessary to wait years in order to test the guaranteed performance of the cooling plant. I think that a communication on this point indicating a method of determining the performance of a cooling plant over a range of temperatures and various hygrometric states of the atmosphere, and incidentally whether it is in accordance with the guarantees would be interesting and useful, and might possibly lead to considerable economies. Mr. Simon.

Mr. W. B. SAYERS: I would like to ask Mr. Neilson whether, in taking the vacuum, he had considered Parsons' vacuum augmentor, and whether he had used that particular appliance. Mr. Sayers.

Mr. M. G. S. SWALLOW (*communicated*): The curves which the author has deduced from his calculations are of considerable assistance in showing what vacua should reasonably be aimed at. The advantages of reduced steam consumption, especially in the case of steam turbines, resulting from the use of high vacua, are so tempting that the cost of obtaining these is apt to be overlooked. The author has dealt exclusively with the ordinary surface condensing plant, but it would be an interesting point to ascertain the effect of the use of jet condensers, and also how far the Parsons vacuum augmentor in conjunction with surface condensing plant will affect the economical vacuum. The use of an augmentor will lower the first cost of the condensing plant and probably also of the power for driving the pumps, even if the steam required by the augmentor is taken into consideration. The net result therefore will be to increase the vacuum for the same temperature of cooling water with a reduced capital outlay. With an ordinary surface condensing plant, moreover, it is hardly economical to aim at a vacuum, the corresponding temperature of which is less than 35° above the inlet temperature of the circulating water, whereas with an augmentor this figure could probably be reduced to 25° and still be within the economical limits. In the case of low load factors the question of banking losses will require serious consideration, as with a load factor of about 10 per cent. half the number of boilers would have to be banked during the greater part of the day, this banking being necessary both on account of meeting any sudden large demand, and also on account of it being more economical to bank the boilers than to drop the fires entirely for a given period. Mr. Swallow.

Mr. R. J. KAULA (*communicated*): I wish to ask the author what assumptions he has made with regard to the following details: Inlet temperature of cooling water; difference in temperature between outlet temperature of cooling water and temperature corresponding to the vacuum; total head against which the circulating pump has to work. Mr. Kaula.

Mr. Roy. Mr. W. H. Roy (*communicated*): The author states in his opening paragraph that it is a more complicated problem to determine the most economical vacuum for a new station or an extension of a station than to determine the best vacuum for an existing plant. It would have been more correct to say that the greatest practical difficulty arises when turbines are added to an existing plant working non-condensing, or working condensing with a limited ground area available for cooling towers. Therefore in omitting to make any allowance for ground area occupied by cooling towers (page 687) he omits an important practical factor in the problem. In some cases the ground area available is so limited that fan draught has to be adopted. In other cases an attempt is made to obtain greater efficiency in the cooling plant as regards heat dispersion per unit area by increasing the height of the tower from 70 ft. to 80 ft., or even 90 ft., and at the same time increasing the static head on the cooler pump from 22–25 ft. to 30–35 ft., with proportionate increase in power. Published test figures in a case where turbines have been installed for extensions, and the surface condensing plant coupled up to existing fan cooling towers and pipework, show 6 per cent. of electrical output absorbed in driving condenser auxiliaries at full load to obtain 27·5 in. vacuum (30 in. barometer) as compared with 2 per cent. given by the author, Table I., line 7 (power to drive fans not included in the 6 per cent.). So far as I have been able to check the figures in Table IV. for cost of condensing plant and cooling towers, they appear to be taken out on a sound basis. The design of surface condensers and pumps has now been so much standardised that no great discrepancy occurs between prices and guarantees put forward by rival makers of good standing, but great discrepancy is often found between prices and guarantees submitted by makers of cooling plant. The figures in Table IV. will cover the provision of first-class and durable plant, including foundations, and the allowance of 10 per cent. for depreciation, repairs, and maintenance is ample. Cooling plant designed for the "lowest tender" class of business could be obtained at lower figures than those given in Table IV., but the allowance for depreciation and maintenance would have to be increased at least to 15 per cent. Cooling plant for turbine service should be designed to reduce the temperature of water to 75° F. under average atmospheric conditions. Assuming 15 lbs. steam per kilowatt-hour, the minimum permissible area for a cooling tower may be taken as 1 sq. ft. per kilowatt to obtain 27·5 in. vacuum in a surface condenser, or 28 in. in a direct-current jet condenser. This means 15,000 to 16,000 B.Th.U. dispersed per hour per square foot area tower, with a static head of, say, 22 ft. on cooler pump, and 1 per cent. of output absorbed in lifting water to cooler. Dividing B.Th.U. per foot area by static head, we obtain an efficiency factor of, say, 700 to 750. Some published figures show a factor of about 500 to 550 from towers by different makers working under average atmospheric conditions, and reducing water to 75° F. Commercial statements are also publicly available claiming a cooling tower efficiency (actual or "guaranteed")

which works out to a factor of about 1,000 on above basis. This factor of efficiency, we may point out, is purely an arithmetical ratio, and does not equate capital charges on cooling towers and foundations with operating costs for pumping water. Published test records, tabulating on a scientific basis the actual performance of cooling towers, are very scanty, and calculations which include the capital charges and operating costs for cooling towers as a definite factor should be handled with considerable caution if reliable deductions are to be made. **Mr. Roy.**

Mr. R. M. NEILSON (*in reply*): Some criticism has been made as to my employment of the term "plant load factor." It may be that in some cases where I have used this term it would have been conducive to greater clearness if I had employed the term station load factor. It should be noted, however, that the conclusions given in the paper are not affected by the expressions employed. If the several steam-electric units in a station are all equal and similar, and if they are equally employed, then the load factor of each unit is the same as the load factor of the station; and, even if the units are not equally employed, the mean load factor of the several units is the same as the station load factor. The case would be different in a station where, say, several reciprocating engines running with moderate vacuum were employed along with a single turbine running with high vacuum, and the reciprocating engines were used only when the turbine could not carry all the load. In such a case the load factor of the turbine would be very different from the station load factor, and this fact would require to be taken into account in connection with its condensing plant. Several speakers have asked me if I have considered the question of using Parsons' vacuum augmentor; and the question of using jet condensers has also been introduced into the discussion. My investigations, as set forth in the tables and curves, have been confined to plant employing surface condensers without the use of vacuum augmentors. The case, as considered, was complicated enough; but the case of jet condensers, or a surface condenser with vacuum augmentor, could be quite well considered. A fresh set of calculations would be required for each of these cases. Mr. J. A. Robertson expressed himself as of the opinion that the economical limit of vacuum is reached somewhat higher than found by me. I would like to be sure that Mr. Robertson, in arriving at this conclusion, is considering the question from the same standpoint as myself, namely, that cooling towers are employed. If, instead of having to depend on relatively hot water obtained from cooling towers, cold water from the sea, or some other natural source, is obtained, it will pay to push the vacuum very much farther. Mr. Robertson also queries the figures in Table IV., where the condensing plant for 28½ in. vacuum is represented as costing nearly double that required for 28 in. vacuum. The great difference in cost is explained by the small number of heat units which can be put into each pound of condensing water when working at 28½ in. vacuum. The temperature corresponding to 28½ in. vacuum is 92° F. and the water is assumed to **Mr. Neilson.**

Mr. Neilson.

leave the cooling tower at 82° F., so that only 10° of rise are possible. With 28 in. vacuum, the greatest possible rise in the temperature of the water is nearly 18° in place of 10°. Mr. Robertson asked if I had allowed for the increased efficiency of the turbines with rise of vacuum. I have done this, and the allowance is shown in line 2 of Table I. As a rule, I believe, the allowance which should be made for change in vacuum per inch of rise is not constant, but increases as the vacuum increases.* Mr. Robertson referred to the use of separate air and water pumps. The whole question of condensing plant is receiving very great consideration at the present moment. Many improvements have recently been effected, and very important developments may be expected. Mr. G. L. Black, if I have taken him up right, has referred to an important point which has been allowed for in my investigation, namely, that the condensing plant cannot be run so economically at low load as at full load. Mr. S. A. Simon has referred to the difficulty often experienced in testing the guaranteed performance of a cooling tower. Station engineers in ordering cooling towers should, I consider, insist on guarantees being given of such a nature that tests of the guaranteed performance can readily be made. The present practice as adopted by many engineers is inclined to encourage the guaranteeing of impossible performances. As regards the last sentence of Mr. Swallow's interesting remarks, I have allowed for banking losses in the figures given for coal consumption. As regards Mr. Kaula's queries, I would reply that the assumptions I have made on the points he raises are as follows: Inlet temperature of cooling water, 82° F.; difference between outlet temperature of cooling water and temperature corresponding to the vacuum, 10½° at 25 in. vacuum, 9½° at 26 in. vacuum, 8° at 27 in. vacuum, 7° at 27·5 in. vacuum, 6° at 28 in. vacuum, and 4½° at 28·5 in. vacuum; the total head against which the circulating pump has to act I have taken as 28½ ft. at 25 in. vacuum, and 58 ft. at 28·5 in. vacuum, with intermediate heads for intermediate vacua. Mr. Roy, in his interesting remarks, refers to my omitting to make allowance for the ground required by the cooling tower. I have given my reasons in the paper for not allowing for the variation in the cooling tower ground. I have certainly not allowed for the interesting case suggested by Mr. Roy in which raising the vacuum would necessitate employing fan draught. This would have a very considerable effect on the power consumption of the auxiliaries. Mr. Roy says that cooling plant for turbine service should be designed to reduce the temperature of the water to 75° F., under average atmospheric conditions. Such a performance by a cooling tower must be considered good under average atmospheric conditions. For vacua of 27 in. and under, it is, I consider, questionable if it would not be better to be content with a higher temperature and reduce the cost of the tower. I endorse Mr. Roy's remarks about the different amounts which should be allowed for depreciation and maintenance in cooling towers of different types or by different makers.

* See "The Steam Turbine," by R. M. Neilson, 4th ed., p. 433.

THE TESTING OF RUBBER FOR ELECTRICAL WORK.

By Professor A. SCHWARTZ, Member.

(*Paper received from the* MANCHESTER LOCAL SECTION, *December* 2, 1909, *and read at Manchester on January* 11, 1910.)

SUMMARY OF CONTENTS.

1. INTRODUCTION.

The physical properties of rubber of which use is made in the arts are its elasticity, compressibility, extensibility, tenacity, flexibility,

adhesiveness, resistance to certain chemical agents, impermeability to water, solubility in certain liquids, and high electrical resistance and dielectric strength.

These properties are called for either singly or in various combinations in one or other of the many applications to which rubber is put in the electrical industry; its insulating power is, however, in most cases, of paramount importance.

Unfortunately, purely electrical tests do not afford satisfactory indications as to the permanence of those qualities of the rubber upon which its power of insulation depends.

For information on this head we must turn, therefore, to the physical and chemical tests. It is now beginning to be recognised that more reliance can be placed in the indications given by physical tests on rubber as to its suitability for electrical work than in those yielded by chemical analysis.

The true function of the physical tests in this connection is to deal with *effects*, while that of the chemical tests is the determination of the *causes* which produce these effects.

The physical tests are, therefore, pre-eminently the tests for the purchaser of the material; they should also form the primary tests of the manufacturer, the chemical tests being supplementary to these either as confirmatory tests or for the elucidation of the causes of the defects indicated by them.

The physical properties of rubber are so varied and so complex that it would be impossible to deal adequately with them within the limits of a single paper; this paper will, therefore, be restricted to a general consideration of the testing of rubber in tension, and to the hysteresis test in particular.

2. Tensile Tests.

Tensile tests may be applied to rubber in the following ways:—

Variable Load Tests.—(*a*) The application of a series of loads of increasing and decreasing magnitude, the load in each instance being added or withdrawn in one operation, the specimen starting from and returning to a condition of no-load in each case, the amount of the successive extensions and retractions being noted.

(*b*) The application of a load which is increased and diminished at a given rate either *per saltem* or gradually, the specimen remaining under tension until the completion of the test. The extension and load at breaking, or the relative loads and extensions up to a given limit of either load or extension, being noted.

(*c*) The extension of the specimen at a given rate, the relation between the load and the extension being noted throughout the test.

Constant Load Test.—(*d*) The application of a given load *per saltem*, the initial extension and the subsequent slow stretch being noted with reference to time.

Constant Extension Tests.—(*e*) A constant extension of the specimen,

the decrease in the tension necessary to maintain this extension being noted with reference to time.

(*f*) A constant extension of the specimen for a given time; on release the sub-permanent set is measured, and after a further period, during which the specimen is at rest, it is again measured, the initial amount of set and its decrease with time being the quantities sought.

(*g*) The specimen is submitted to a series of successive extensions and retractions of a given amplitude, the load being applied and removed at a given rate. The number of cycles of extension and retraction completed before the specimen breaks is noted.

These tests may be applied in the first instance to the rubber specimens in the condition in which they are cut, and subsequently to similar specimens which have been artificially aged by the action of heat, ozone, light, etc., the objects of the latter tests being to secure some indication as to the probable durability of the rubber.

At the present time the tensile tests in common use are restricted to the determination of the load and elongation at breaking, and the amount of sub-permanent set retained by a specimen which has been kept extended to a given limit for a certain number of hours, the set being measured on release and again after a period of rest.

It will be seen that the results yielded by these tests are concerned with the behaviour of the rubber at the end of the tests only; in the author's view far more valuable results are to be obtained from tests in which the behaviour of the rubber is noted throughout the tests.

In the *per saltem* tests with variable load—method (*a*)—the specimen is supported vertically, the upper end being clamped in a fixed grip, while weights are added to or withdrawn from a light scale pan attached to the lower end of the specimen. This method is somewhat clumsy and difficult to work with, as the weights have to be added and withdrawn by hand to the beats of a metronome. The results obtained do not differ from those obtained with an oscillatory load as in method (*g*), and the only merit of the method lies in the simplicity of the apparatus. In the *per saltem* test at constant load—method (*d*)—the same apparatus is used as in method (*a*), but only one weight is employed. The machines for testing rubber in tension under varying load—methods (*b*) and (*c*)—now on the market are modelled very closely on the type of machine which has for many years past been employed in the testing of textile fabrics. These machines as a rule test the specimens to destruction, and so take no account of the retractive power of the rubber, and they record merely the load and extension at breaking. A critical discussion of the leading types of rubber-testing machines has recently been published by Schidrowitz,* and may be consulted with advantage for details of these machines.

Most of these machines are designed so that a variety of tests may be performed with them. In designing the machine to be hereinafter described, the author had a specialised aim in view, namely, the testing of rubber cable coverings. At the same time, the principle of the

* *The Indiarubber Journal*, May 17, 1909, p. 563 *et seq.*

machine lends itself quite readily to the testing of a variety of rubber articles, and, as the author wishes to place the machine entirely at the service of the industry without any restriction, such modifications in detail as may be necessary to increase its scope may easily be effected by those concerned.

The details which are chiefly affected by the character of the work for which a machine is specially intended are the form of the test-pieces and the character of the grips.

3. Test-pieces and Grips.

The essential condition that a test-piece when in tension shall not slip at the grips is that the product of the pressure developed in the grip and the coefficient of friction shall be greater than the breaking load of the specimen.

Assuming that the volume of the specimen remains constant throughout the test—which is very nearly the case—it is evident that in the case of a high-grade rubber, which extends to 8 or 10 times its original length before breaking, the material must flow to a very considerable extent, whereas with a lower grade rubber, with an extension of only 100 per cent. or 200 per cent. at breaking, this flow is very much less. The author finds that rectangular test-pieces of uniform width throughout give satisfactory results with low-grade rubbers, the specimens breaking outside the grips, but that with high-grade rubbers the failure takes place at the grip. The difficulty of breakage at the grips may be minimised or avoided in the following ways :—

(*a*) The employment of a ring-shaped test-piece punched from a sheet and stretched between two pulleys which may be rotated during the test so that local crushing of the specimen is avoided (Schopper).

(*b*) The employment of a test-piece with expended ends shaped like a cement briquette.

(*c*) The reinforcing of the ends of the test-piece with rubber pieces joined to them by solution.

(*d*) The diminution of the stress on the rubber before entering the grips by passing the specimen round a smooth cylindrical surface close to the grips.

(*e*) The employment of a single grip with a test-piece of rectangular section and uniform width, and the restriction of the maximum load of the test to a value below that of the breaking load of the specimen.

The ring-shaped test-piece undoubtedly gives the best results in the determination of the breaking load, and is well suited for investigation work on the physical properties of rubber. In the case of cable coverings it can only be used for the large sizes, and in the case of a large number of rubber articles its use would necessitate the preparation of special sheets from which the test-rings could be punched. These sheets would have to be made from the same compound as the articles concerned and vulcanised with them. This method is in use in the

United States* and in this country † and should give good results with articles of uniform thickness. It is essential, however, that the test-sheet should be of the same thickness as the articles concerned if the same degree of vulcanisation is to be secured.

The employment of a test-piece with expanded ends is also difficult in the case of cable-coverings, and in many cases would necessitate the making up of special test-sheets from which the specimens could be cut or punched. The relation between the load and corresponding extension in such test-pieces will depend upon the size and shape of the test-pieces adopted if the elongations are to be measured between the grips. This form of test-piece is, however, desirable for the determination of the breaking load.

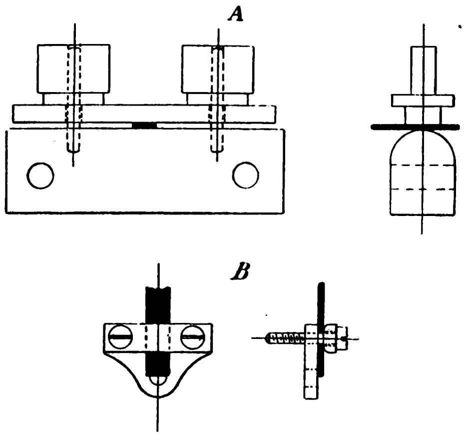


FIG. 1.—Test-piece Grips for Hysteresis Machine.

A—Fixed grip.
B—Movable grip.

The reinforcing of the ends of the test-piece is likely to lead to discordant results owing to the action of the rubber solution on the specimen.

The diminution of the stress in the rubber by passing the specimen over a cylinder in the way referred to before entering the grip is tantamount to increasing the length of the specimen and therefore (for an extension which is a given multiple of the initial length of the specimen) the length of travel of the movable grip. The radius of curvature of the surface round which the specimen is passed should be fairly large and the specimen must be served with French chalk to prevent

* Schidrowitz, *loc. cit.*

† "A Machine for the Mechanical Testing of Indiarubber," by Clayton Beadle and H. P. Stevens, *Journal of the Society of Chemical Industry*, vol. 28, p. 1111, 1909.

abrasion. The relation between the load and the extension will depend upon the total length of the test-piece and the diameter of the cylinder adopted.

Having experimented with the above forms and with plate grips with diamond roughing and with grips with a series of transverse grooves with rounded edges in both top and bottom plates which lock into one another when the grip is closed, the author has discarded them all in favour of the simple grip shown in Fig. 1.

This grip is intended for use in the hysteresis test, in which the maximum load employed is less than the breaking load of the specimen. At the same time the values of the breaking load as determined with it are consistent, although they are probably for high-grade rubbers slightly lower than those obtained with annular test-pieces tested between rotating pulleys.

The test-pieces used by the author, except in the case of the smallest

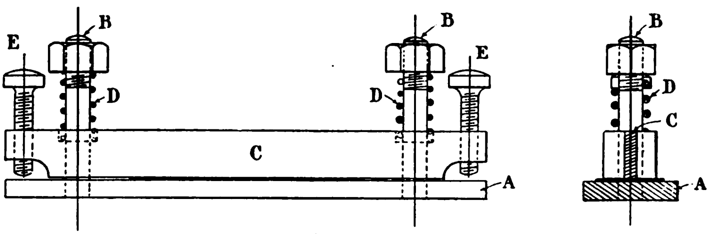


FIG. 2.—Block for Cutting Rubber Test-pieces under Constant Pressure.

cables and wires, are ¼ in. wide throughout and 4 in. long over all, giving 3 in. clear between the grips.

They are cut on a special block shown in Fig. 2, which consists of a metal base A, with two vertical studs B, upon which the gauge-bar C, which is ¼ in. wide, slides. The gauge-bar is held down on the rubber to be cut by the pressure of two springs D, under the heads of the studs B. The gauge-bar carries at each extremity a set screw E; by screwing these down on the base-plate the gauge-bar is raised for the admission of the rubber; when the latter is in position the set screws are slacked back.

In preparing the test-pieces the procedure is as follows: In the case of cables of large size a length of about 9 in. of cable is cut off, the braiding and tapes are then removed, and a single straight cut made right through the rubber along the length of the sample. The rubber is then stripped from the core, care being taken not to stretch it in so doing. The rubber covering when stripped being more than ¼ in. wide will allow of the test-piece being cut out of it, so the longitudinal cut referred to above need not be made absolutely clean and straight, as its edges will not form the edges of the test-piece. The rubber should be cut on a strip of hard wood placed under the

gauge-bar on the metal base of the cutting block, thus preserving the edge of the knife used in cutting.

For small cables and wires in which the whole width of the rubber covering is required for the test-piece, it is necessary that the longitudinal cut should be quite true. The procedure for small cables is as follows: A couple of 4-in. lengths should be cut, and after straightening and the removal of the braiding, should be clamped in turn with the long axis under one edge of the gauge-bar C on the cutting-block (Fig. 2), and the rubber cut carefully through to the core.

4. Rubber Cutting.

For cutting rubber the author uses an ordinary wireman's knife, or a surgical scalpel, or a good pocket-knife; the blade should be brought to a keen edge for about $\frac{1}{4}$ in. from the point and used nearly vertically, the side of the blade being pressed against the side of the gauge-bar, which is made specially deep for the purpose of ensuring verticality. With high-grade rubbers the cutting should be done under water, the cutting-block being placed in a shallow trough provided for the purpose. With cable coverings, however, it will usually be found sufficient to wet the blade of the knife by dipping it once or twice into water during the operation of cutting.

With high-grade rubbers it is well to take very light cuts, making about a dozen cuts to a thickness of $\frac{1}{16}$ in. Working under water in this way, the pressure required with a keen knife is so light that the action may almost be described as "stroking." With a little practice a perfectly clean-cut, smooth edge may be obtained in this way, both with cable coverings and with sheet, and no trouble will arise from tearing at the edges on the extension of specimens thus prepared. With lower grade rubbers the cutting may be done under increased pressure at the rate of three or four strokes to $\frac{1}{16}$ in. thickness.

Cable coverings should be placed under the gauge-bar in the cutting-block with the pure rubber side uppermost. As the rubber covering is practically moulded round the cable core, it retains a cylindrical form when stripped, and when it is flattened out under pressure for cutting, it will on release tend to return to the cylindrical form so that the cross-section of the specimen when cut is not strictly rectangular. In order to facilitate the placing of the cable covering under the gauge-bar, the strip of hard wood previously referred to should be removed and replaced when the rubber is in position.

After being cut the test-pieces should be dried with a clean cloth, and should be handled as little as possible before testing; care should be taken in all the operations not to stretch the rubber.

5. Mounting the Test-piece.

Except in the case of ring-shaped test-pieces, which are extended between cylindrical pulleys, and which are therefore not, strictly

speaking, "gripped" at all, a difficulty is experienced owing to the extrusion of the rubber from the grips as the latter are screwed down. This extrusion increases the length of the specimen between the grips by a small amount depending upon the thickness and quality of the rubber employed. It is, of course, desirable in every case that the length under test should be standard if reliable comparative results are to be obtained, and this is particularly the case in recording

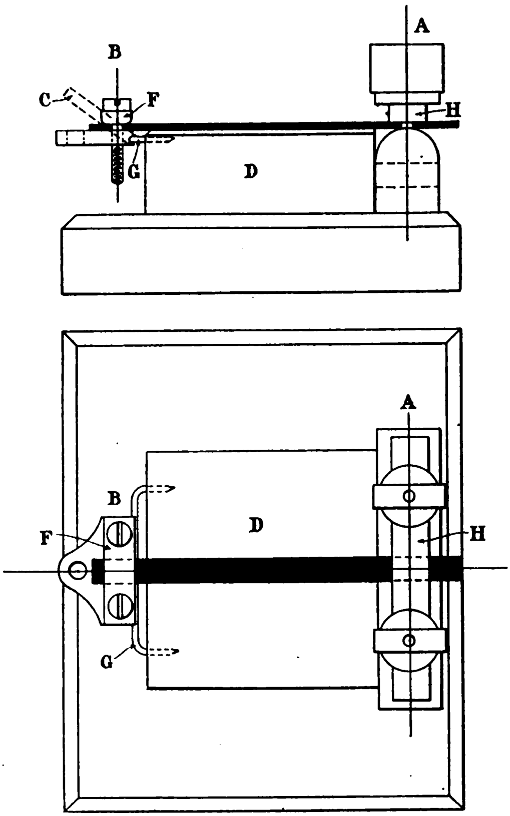


FIG. 3.—Block for Mounting Test-pieces in Grips.

machines, as any difference in the initial lengths of the specimens to be compared will alter the line of zero extension on the chart of the machine.

In the author's machine for testing cable coverings the fixed grip is of solid construction, whereas the movable grip to which the load is applied is made as light as possible. The arrangements for mounting the test-pieces are shown in Fig. 3, where the wood mounting

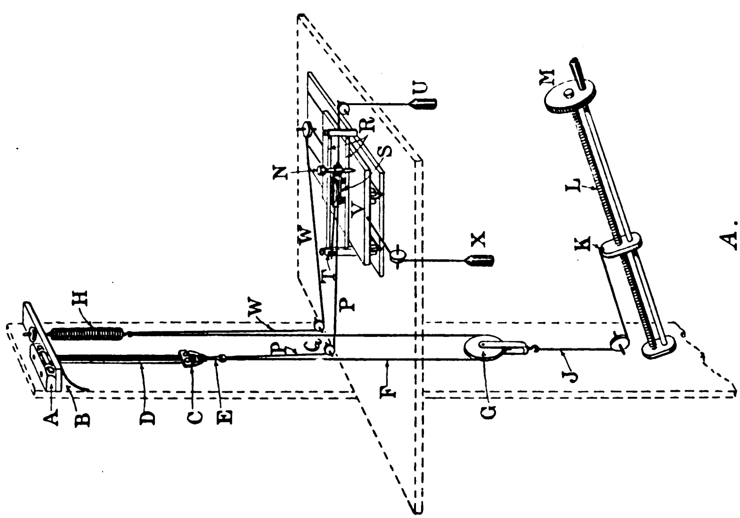
block D is of such a size that the length of the specimen E between the centre lines of the fixed grip A and the movable grip B when in the positions shown is exactly 3 in. One end of the test-piece is inserted in the movable grip B and the pinch-bar F screwed down as tightly as possible—this grip carries on its front edge a semicircular groove, and the grip with the test-piece in it is then placed against the block D, so that this groove engages with the cylindrical bar G. The other end of the test-piece is then passed beneath the pinch-bar H of the fixed grip A, and the protruding end is then pulled so as to tilt slightly the movable grip B to the position shown in broken line at C. The pinch-bar H is then screwed down until the rubber extruded in so doing allows the movable grip to fall again to a horizontal position. The amount of tilt which it is necessary in the first instance to give to the movable grip B depends upon the thickness of the specimen and the character of the rubber; a little experience, however, soon enables it to be easily gauged correctly.

6. The Hysteresis Machine.

The object of this machine is to effect the extension of the rubber by means of a load which is increased at a given rate until either a given load or a given extension is attained. When this point is reached the load is diminished at the given rate and the rubber is allowed to retract, the relation between load and elongation being recorded automatically throughout the test. The machine is shown in Fig. 4. The test-piece having been secured in the grips the fixed grip A is mounted on the pins on the bracket B, and the movable grip C, which depends from the specimen D, is connected by the removable hook E to the cord F, which passes round the floating pulley G to the helical spring H, the load is applied and withdrawn by the up and down traverse of the pulley G, which is effected either by means of a small hydraulic cylinder, the rate of movement of the piston of which is controlled by a byepass; or as shown in the figure by the cord J, which is attached to a nut K, which is moved along a guide by the scew L, which is turned by hand at M.

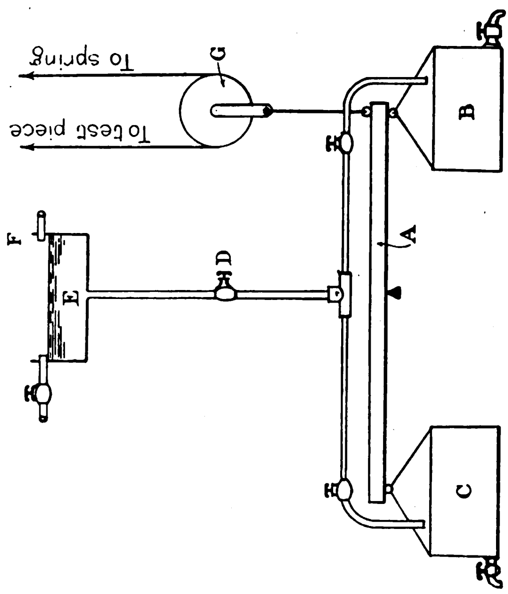
It will be seen that an even rate of motion of the pulley G does not necessarily result in an even rate of extension or retraction of the test-piece nor in an even rate of increase or decrease in the load upon it. Since the movement of the pulley G is shared between the test-piece and the spring H, the action is a differential one, the extension of the spring being directly proportional to the load while that of the test-piece depends upon the nature of the rubber under test. Provided, however, that the rate of movement of the pulley G is kept within certain limits, the results obtained are identical with those produced by increasing the load at a constant rate.

The relation between load and extension is charted in the following way: The grip C, the movement of which represents the extension, is connected to the pencil carrier N by the thread P which passes over



A.

FIG. 4A.—Diagram of Hysteresis Machine.



B.

FIG. 4C.—Diagram of Arrangements for Loading at an Even Rate.

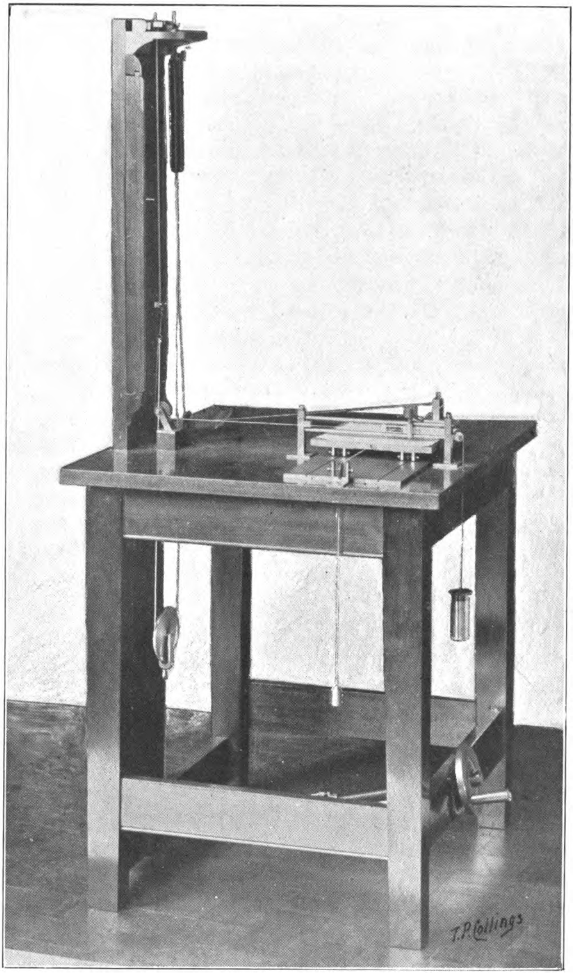


FIG. 4B.—Complete Machine.

the pulley Q. The pencil carrier which moves between the guides R contains a pulley S, round which the thread P passes to a stop T which is adjustable as to position, where it is made fast. The movement of the pencil is thereby reduced to one-half of the extension of the specimen. If necessary this movement may be again reduced by one-half by the introduction of a light floating pulley in the thread P. The movements of the pencil carrier are controlled by the counterweight U. Beneath the pencil carrier and moving at right angles to it is a light table V on which the chart paper is fixed, the movement of this table is directly proportional to the load as it is attached to the spring H by means of the thread W. The movement of the table is controlled by the counterweight X.

For carrying out tests in which the load is increased or decreased at a given rate the pulley G is connected as shown diagrammatically in Fig. 4C to one end of the balance arm A, from which two cans, B and C, are slung. The load is added by running water at a given rate into the can B, and removed by running water into the can C at the other end of the balance arm at the same rate as before.

The rate of flow of the water is determined by the cock D, and the head of water is kept constant by feeding from a small tank E provided with an overflow F, which is kept running throughout the test. This apparatus is not required for commercial tests since the same results are obtained if the movement of the pulley G be obtained from the hydraulic cylinder, or the hand-fed screw provided that the rate of movement of the pulley G is kept within the limits to be stated hereafter.

7. Hysteresis Loop Limits.

The hysteresis loop furnishes us with a graphical record of extension of the rubber test-piece as the load is increased from zero to a given maximum and then decreased again to zero. In this case the limits between which the curve is drawn are expressed in terms of load, the maximum load being usually 80 or 90 per cent. of the breaking load of the specimen.

As an alternative to this the limits for the curve may be expressed in terms of extension. In this case the rubber is stretched until a given extension is obtained; such extension may be conveniently expressed as a percentage of the original length of the specimen or as a multiple of that length.

While the hysteresis loop with a limit in terms of load (say 90 per cent. of the breaking load) probably gives the truest indication of the individual merits of the coverings tested, yet it depends upon the accuracy with which the breaking load is determined. As already pointed out, with high-grade rubbers the breakage will take place at the grip, and in order to obtain consistent results at least three specimens should be cut and extended to the breaking-point.

The author therefore finds it more convenient to set the limit in

terms of the extension, and since the main objects of these tests is to discriminate between rubbers which are presumed to be of a given standard grade, the limits of extension can be arbitrarily settled for the different grades.

Taking as an example coverings for $\frac{19}{16}$ cable in 2,500- and 600-megohm C.M.A. grades it will be found that when new the higher grade coverings have extensions at breaking of between 300 per cent. and 400 per cent., while the 600-megohm coverings break with extensions varying from 200 per cent. to 300 per cent. So that if we decide upon an extension limit of 300 per cent. for the hysteresis loop for the 2,500-megohm grade and of 200 per cent. for the 600-megohm grade coverings we shall have set limits which are suited to these two classes.

In the same way, if the limit to the hysteresis loop is set in terms of load we should have to determine standard limits for the two grades with which the results of the tests should comply.

8. Physical Quantities Obtainable from the Hysteresis Loop.

The physical quantities which may be obtained from a hysteresis diagram drawn between limits of load or extension are set out as follows in connection with Fig. 5 :—

1. The rate of extension with load: this is given at any point on the extension curve O B by the inclination of the tangent at that point. The rate of retraction in a similar way may be obtained from the retraction curve B D.
2. The work done in extension : this is given by the area O B C O.
3. The work done by the rubber in retracting : this is given by the area D C B D.
4. The work expended in the rubber itself : this is given by the area of the loop O D B O.
5. The sub-permanent set remaining after a given extension : this is measured by the length of the line O D.

9. Characteristic Forms of Loops.

With a normally vulcanised standard specimen of high-grade rubber stressed nearly to its breaking-point, the extension curve may be divided into three distinct portions in which the relation between load and extension differs considerably.

Considering the extension curve O B Fig. 5, we see that in the first portion (stage 1) the increase in extension per unit of load is small, and that for the middle portion of the curve between (stage 2) it becomes much larger, and is practically constant, falling again on the last portion of the curve (stage 3).

With high-grade rubbers which are correctly vulcanised and with rubbers which are under-vulcanised or contain a small proportion of substitute, stages 1 and 3 are small, while stage 2 is large.

With hard rubbers which are over-vulcanised or contain a large proportion of mineral matters, stages 2 and 3 are small or suppressed and stage 1 is large.

As these forms of extension curve are characteristic of certain classes of rubber with specimens of standard size extended to a given limit, it is suggested that they be distinguished according to the form of front that they present to the axis of load. Thus the designation of the types of extension curves, of which the dominant characteristics

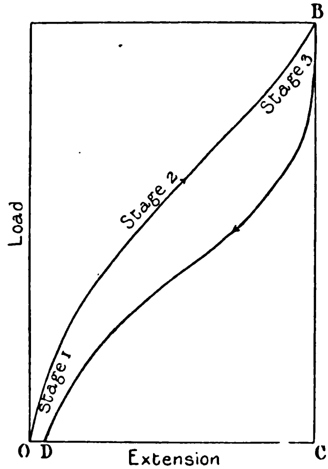


FIG. 5.

were as in stages 1, 2, and 3 (Fig. 5) respectively, would be as follows :—

Dominant character as in—	Designation of extension curve.
Stage 1.	Convex.
Stage 2.	Linear.
Stage 3.	Concave.
Stages 1, 2, 3.	Convexo-concave.

10. METHODS OF COMPARISON.

The following procedure is suggested for reducing the salient features of a number of hysteresis loops of various rubbers to a common basis for purposes of comparison :—

1. The designation of the form of extension curve as convex, linear, etc., as already suggested.
2. The determination by means of a planimeter or area scale of the areas representing the work done in extending the rubber.

3. The determination of the work done by the rubber retracting.
4. The reduction of the areas in (2) and (3) to their equivalent triangles on a given base.

The areas under (4) may be reduced to their equivalent triangles by multiplying the area by two and dividing by the length of the base, the base being extension or load, according as one or other of these quantities is used for the limits of the hysteresis loop.

Example (see Fig. 6) :—

Cable covering $\frac{19}{18}$, 2,500-megohm grade.
Test-piece, 3 in. × $\frac{1}{4}$ in. × 62 mils.
Extension scale ($\frac{1}{2}$ in.), 1 in.
Load scale ($\frac{3}{8}$ in.), 1 lb.
Form of extension curve, convex.
Area representing work done in extension, 3·56 sq. in.
Area representing work done in retraction, 1·46 sq. in.
Sub-permanent set, 0·40 in.

Reducing these areas to triangles on a base of extension, we have—

Extension Work.—Height of triangle (C A)—

$$= \frac{\text{extension work} \times 2}{\text{length of base (O C) in inches}},$$
$$= \frac{3{\cdot}56 \times 2}{3},$$
$$= 2{\cdot}37 \text{ in.}$$

The base for the retraction work triangle will be the actual distance moved through in retraction—that is, the maximum extension minus the sub-permanent set (O C — O D).

Retraction Work.—Height of triangle (C B)—

$$= \frac{\text{retraction work} \times 2}{\text{scale length of retraction in inches}},$$
$$= \frac{1{\cdot}46 \times 2}{3 - 0{\cdot}40},$$
$$= \frac{2{\cdot}92}{2{\cdot}6},$$
$$= 1{\cdot}10.$$

We have now embodied in the equivalent triangles the whole of the quantities above referred to as follows (see Fig. 6) :—

1. The slope of the lines O A and B D represents the average rates of extension and retraction respectively per unit of load.
2. The area of the triangle O A C represents the work done in extension.

3. The area of the triangle D B C represents the work done by the rubber in retracting.
4. The area O A B D O represents the work done in the rubber itself; its numerical value is obtained by subtracting the area of the triangle D C B from that of the triangle O A C.
5. The sub-permanent set is measured by the length of the line O D.

11. Constancy of Results.

With homogeneous material, the loops obtained with the hysteresis machine are identical for any number of standard specimens of a given material, and are, therefore, characteristic of the material.

It must, however, be borne in mind in this connection that freshly vulcanised rubber improves with keeping, and takes some time to settle down to a constant state, so that if comparative tests are to be made on a number of samples which are newly manufactured care should be taken that they are all of the same age (say 10 days).

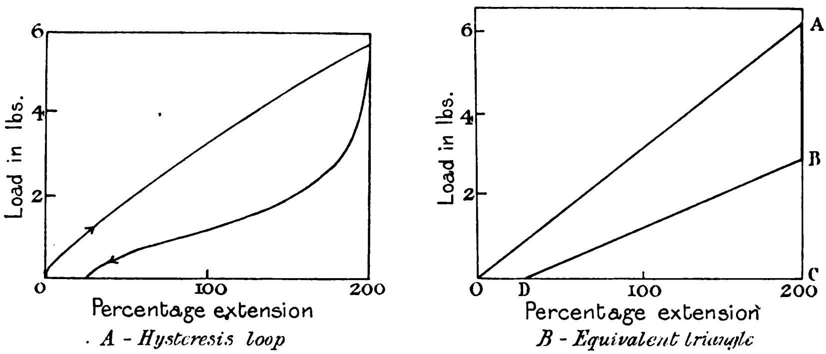


Fig. 6.—Reduction of a Hysteresis Loop to its Equivalent Triangle.

The author has found that the 2,500-megohm C.M.A. coverings that he has tested are very homogeneous, but he has occasionally come across samples in the 600-megohm grade taken within a couple of feet of each other from the same cable covering which give different loops, one loop being very much harder than the other, due evidently to faulty vulcanisation.

It is well to cut three test-pieces from each sample to be tested, and after obtaining the loop for the first one to leave the chart paper in position for the second and third; the curves from these, if correct, should be practically coincident.

This procedure is necessary to allow for the inequality in manufacture; taking, for example, a $\frac{19}{16}$ covering, this is sufficiently wide to allow of three test-pieces $\frac{1}{4}$ in. wide being cut abreast from a 4-in. length. It is probable that one of these will contain a longitudinal

joint, or the core may not have been quite central. Fig. 7 shows the loops for the 1st, 2nd, and 3rd cycles for a 2,500-megohm covering by Firm G; the curves are reproduced from the actual chart taken from the machine. The curves marked a_1, a_2, and a_3 are each made up of four lines which are very nearly coincident, each of these lines being traced

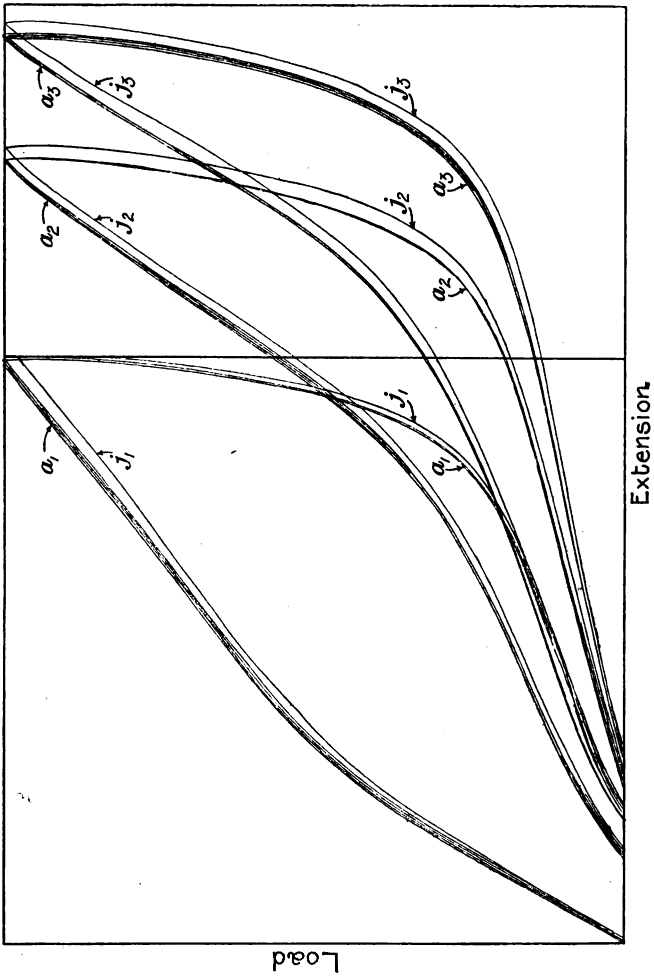


FIG. 7.—Reproduction of Actual Diagram showing Constancy of Results obtained with the Hysteresis Machine.

Test-pieces cut from 2,500-megohm covering, and put through three cycles of extension and retraction. Curves a_1, a_2, a_3 are made up of four lines, each due to a separate test-piece. Curves j_1, j_2, j_3, due to a single test-piece cut from the same covering as the others, but containing a longitudinal joint.

by a separate test-piece which was taken through three cycles of extension.

The curves marked j_1, j_2, and j_3 were traced by a single test-piece which had a longitudinal joint along its centre line, which has caused the slight deviation shown.

12. Effect of Variation of Temperature.

Experiments were made with standard test-pieces of 88 per cent. Para by firm A, 40 per cent. Para by firm G, and 2,500-megohm C.M.A. cable covering by firm E.

The specimens were exposed for seven hours at temperatures of 65° F. and 50° F., and their hysteresis loops were then taken with an extension of 150 per cent. The loops obtained with the 88 per cent. rubber were practically identical for the change of temperature of 15° F., those for the 40 per cent. rubber showed an increase in loop area of 1·3 per cent. per 1° F. fall in temperature, while the load required to give the necessary extension increased 0·8 per cent. per 1° F. fall. The cable covering showed an increase in loop area of 1·1 per

Table I.

Transmission of Heat through Cable Covering.

$\frac{19}{16}$ covering, 2,500 megohm grade, thickness 62 mils.
Temperature external to the covering, 115·8° F.
Room Temperature, 62·6° F.

Time. Minutes.	Temperature inside Covering. ° F.
0	62·60
1	109·40
2	112·60
3	114·80
4	115·16
5	115·34
6	115·54
7	115·72
8	115·72
9	115·72
10	115·72

cent., and of load 0·8 per cent. per 1° F. decrease in temperature. The author's experiments were carried out at temperatures varying from 58° F. to 62° F., and it does not appear from the above results that a small variation in the test-room temperature is likely to present any serious difficulty. The author exposed the specimens used in these experiments to the air at a given temperature for a period of seven hours, out of deference to the current view that rubber is very slow in taking up the temperature of its environment.

From a consideration of the degree of comfort obtainable from a vulcanised rubber hot-water bottle within a very short time of its being filled he was led, however, to make the following experiment on the rate of transmission of heat through a cable covering.

A 6-in. length of 2,500-megohm covering was removed from the

core in the form of a tube, the lower end was securely plugged, and a little mercury poured into the tube so as to surround the bulb of a thermometer placed in the tube. The rubber was then placed in a beaker of water, the temperature of which was kept constant at a temperature of 115·8° F., with the results given in Table I. :—

It would appear, therefore, that about a quarter of an hour would be sufficiently long for $\frac{19}{16}$ covering to attain the temperature of its surroundings.

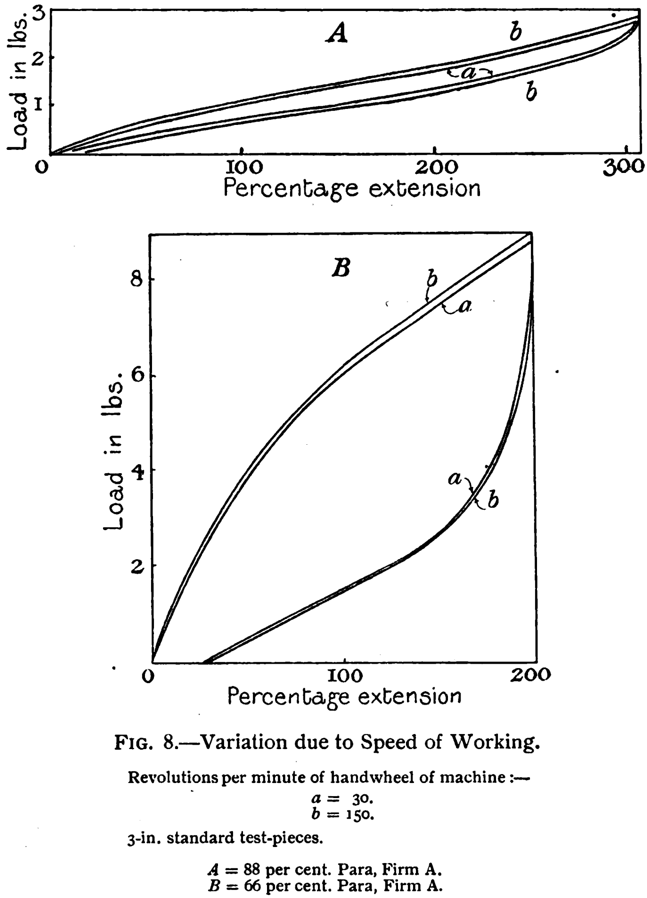


FIG. 8.—Variation due to Speed of Working.

Revolutions per minute of handwheel of machine :—
a = 30.
b = 150.

3-in. standard test-pieces.

A = 88 per cent. Para, Firm A.
B = 66 per cent. Para, Firm A.

13. EFFECT OF VARIATION IN SPEED OF WORKING.

As already explained in the author's machine, the load is applied or removed by the traverse of a nut on a threaded spindle, which is rotated by means of a hand-wheel, 12 revolutions of the wheel giving an inch traverse of the nut.

The variations in the hysteresis diagrams due to varying the speed of rotation of the hand-wheel from 30 to 150 revs. per minute are shown in Fig. 8 for specimens containing 88 per cent. and 66 per cent. of Para rubber respectively.

It will be seen that for commercial purposes this variation is not of great consequence. In the author's tests he adopted a uniform speed of 100 revs. per minute, but he considers 60 revs. per minute would be better for commercial purposes as the timing could easily be

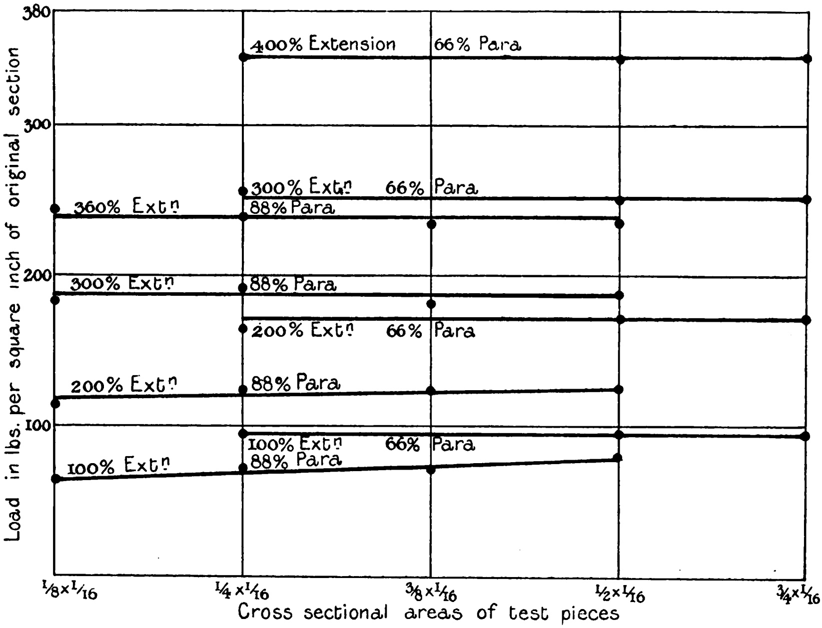


FIG. 9.

The load expressed in pounds per square inch of the original cross-sectional area of the test-piece is constant for a given extension within certain limits.
Test-pieces, 88 per cent. Para, Firm A, 2½ in. long.
Test-pieces, 66 per cent. Para, Firm A, 3 in. long.

done by means of a watch or a loud ticking American clock. Under these conditions the time taken for a complete test given a sample of rubber covering stripped from the core is only about 7 minutes.

14. Cross-sectional Area of Test-pieces.

M. Stévart, an engineer to the Belgian State Railways, carried out over a period of twenty years a series of experiments on rubber remarkable for their simplicity and scientific acumen.* He found that

* A. Stévart, *Bulletin du Musée de l'Industrie*, 1870

for a given extension the load was directly proportional to the cross-sectional area of the specimen. So that if the load be expressed in lbs. per square inch of the original area of the specimen, the load for a given extension will be constant and independent of the cross-sectional area of the specimens, and the total extension at breaking will therefore be independent of the cross-sectional area. Stévart worked with loads below the breaking-points of the specimens, and with strips or rings with a cross-sectional area up to 102 sq. mm., with a ratio of breadth to thickness varying from 1 : 1 to 1 : 2. The author has confirmed Stévart's law for pure rubber strip,* and Dalén, Frank, and Marckwald, and Schopper working up to the full load of rupture have shown that the law holds good for ring-shaped test-pieces 4 mm. wide and varying in thickness from 2·5 to 7·5 mm. The results of the author's experiments with specimens cut from sheet containing 88 and 66 per cent. Para are shown in Fig. 9.

A consideration of this figure shows that for compounds containing up to 66 per cent. Para, which would include most cable compounds, Stévart's law holds good over the range shown. The deviation shown with 88 per cent. Para on 100 per cent. extension is probably explained by the fact that the test-piece was only 2½ in. long and that the lateral flow of the material near the grips was interfered with.

The work done in extension, retraction, and in the rubber itself is proportional to the cross-sectional area of the specimens, as may be seen from Fig. 10, which gives the results for a 3-in. specimen containing 88 per cent. Para and extended for 200 per cent.

It will be noticed that the variation in cross-sectional area in Figs. 9 and 10 is obtained by increasing the width of the specimens with a constant thickness. The author has also experimented with specimens of 88 per cent. Para having a constant cross-sectional area of $\frac{1}{64}$ sq. in. with widths varying from $\frac{1}{8}$ in. to $\frac{1}{2}$ in., and thickness varying from $\frac{1}{32}$ in. to $\frac{1}{8}$ in. with the following results :—

Cross-section in Inches.	Area of Hysteresis Loop in Square Inches.
$\frac{1}{8} \times \frac{1}{8}$	0·41
$\frac{1}{4} \times \frac{1}{16}$	0·44
$\frac{1}{2} \times \frac{1}{32}$	0·49

These specimens were carefully prepared by Firm A, but it is a difficult matter to secure that the amount of vulcanisation is the same with specimens of varying thickness. The above results are important as they enable us to compare the results obtained from specimens with different cross-sectional areas when extended to the same percentage of their original length ; and a direct comparison of the hysteresis loops obtained may be made by means of the equivalent triangles referred to. In this case the areas representing the work done in extension and retraction are increased or reduced proportionally according as the cross-sectional areas of the specimens concerned are less or greater

* *Journal of the Institution of Electrical Engineers*, vol. 39, pp. 64 and 67, 1907.

than the cross-sectional area which is taken as a basis of comparison.

15. Length of the Test-piece.

Experiments were made with test-pieces varying in length from 1 to 5 in., and the results show that for a compound containing 88 per cent. Para and a 200 per cent. extension the work done in extension,

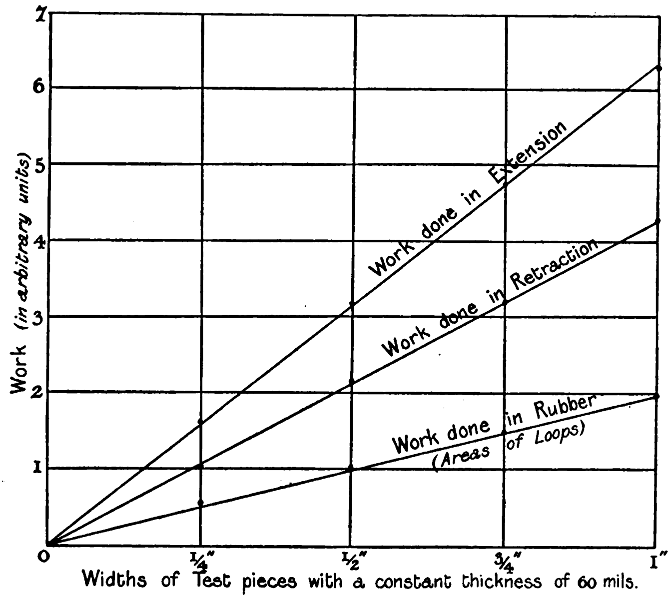


Fig. 10.

The work done in extension, in retraction, and in the rubber itself is proportional to the cross-sectional area of the test-piece within certain limits.
88 per cent. Para rubber by Firm A.
Test-pieces, 3 in. long and 60 mils. thick by various widths.
Extension, 200 per cent.

retraction, and in the rubber itself is directly proportional to the length of the specimen.

A further series of experiments with 88 per cent. Para mixing rolled into sheets which were vulcanised for the following times : ½ normal time, ¾ ditto, normal full time, 1¼ ditto, 1½ ditto, and with specimens 1, 2, 3, 4, and 5 in. long respectively, showed that the work done in extension, retraction, and in the rubber itself, was for a 200 per cent. extension approximately proportional to the length of the specimen multiplied by a coefficient which was proportional to the time of vulcanisation.

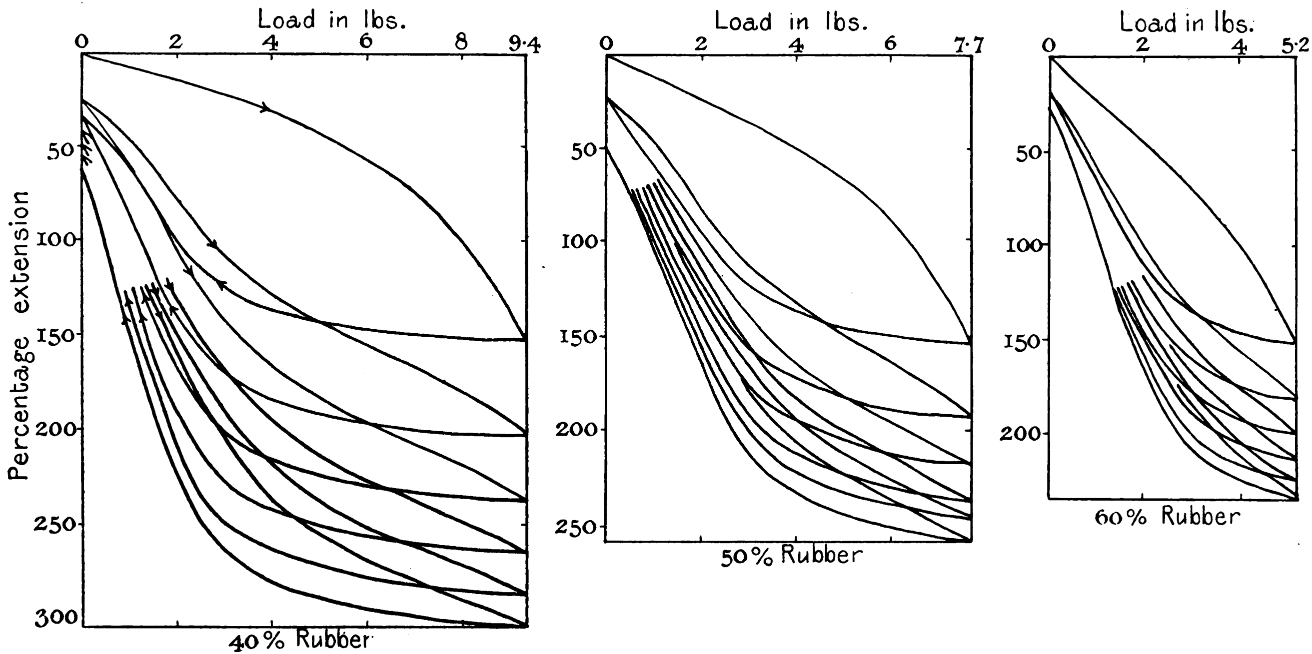


FIG. 11.—Effect of successive Cycles on Specimens containing various Percentages of Rubber by Firm G.

The first cycle in each case is taken up to a maximum extension of 150 per cent.; the load corresponding to this extension is noted, and in the subsequent cycles the specimens in each case are taken up to this load as a maximum. The relation between the various loop-areas and the increments of extension are shown graphically in Figs. 12 and 13.

16. Successive Cycles.

On the completion of the first cycle of extension and retraction the specimen may be retained in the machine and subjected to a series of similar cycles, the limits of which may be set either by a given maximum extension or a given maximum load. For example, if the first cycle for a given specimen has been taken up to an extension limit of 200 per cent., the subsequent cycles can either be taken up to the same extension limit, or they can be taken up to the same load as that which was required to give the 200 per cent. extension in the first cycle.

The extension limit gives a series of curves for the subsequent cycles which lie close together, and are not easily discriminated, whereas the load limit differentiates more strongly between the curves for the subsequent cycles, and therefore lends itself more easily to accurate treatment.

In both cases, however, the area of the loop for the second cycle is much less than that of the first, and the dominant character of the extension curve for the second cycle and all subsequent cycles is that the front is concave to the axis of load in all cases.

Fig. 11 shows how the successive cycle test may be applied to discriminate between mixings containing various percentages of rubber. In this instance, standard test-pieces containing 40, 50, and 60 per cent. of rubber respectively were extended in their first cycle for 150 per cent., and the load corresponding to this extension noted, the subsequent cycles being taken up to this load limit in each case. An inspection of this figure shows that the proportion of rubber in the mixing exercises a considerable influence on the areas of the loops for the first cycles, and also on the increments of extension due to the subsequent cycles.

Fig. 12 shows graphically the variation in the various quantities in the diagrams shown in Fig. 11.

For high-grade rubber (88 per cent.) the areas of the loops for successive cycles become constant after about the 6th loop, and a consideration of Fig. 12 shows that for the 6 cycles given the areas of the loops for the 60 per cent. rubber are more nearly approaching a constant value than those for the lower grade rubbers. Speaking broadly, we may say that for cable coverings the areas of the 6th loop may be taken as constant, and, therefore, characteristic of the material concerned. We see also that the curves of loop areas for the 1st and 2nd loops, and of course for the subsequent loops, also are characteristic of the mixings. The curves for the work done in extension and in retraction in the various cycles are also given, but do not seem to lend themselves so readily to the purpose of discriminating between the mixings.

The length of the specimen after each cycle differs from that of the preceding cycle by the amount of sub-permanent set due to the cycle in question. The author finds that the extension for the given load

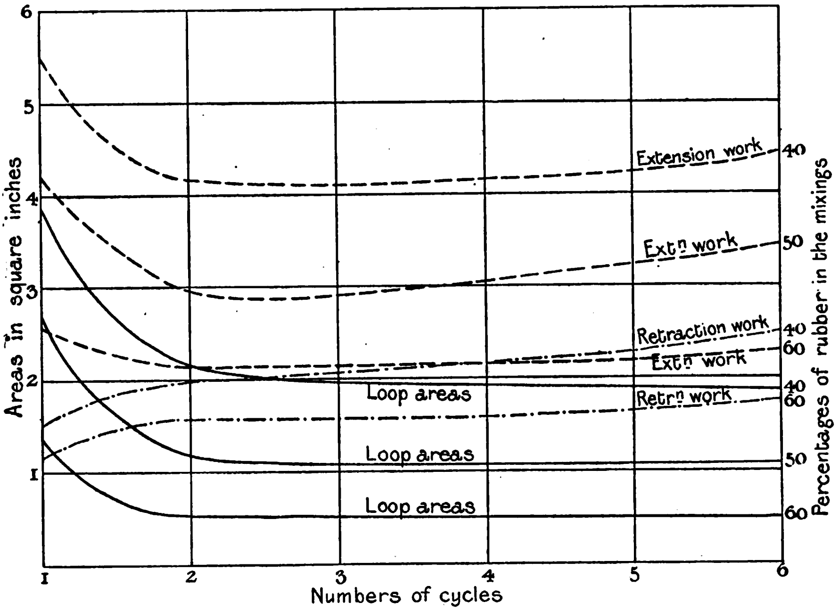


FIG. 12.—Relation between various Quantities for successive Cycles obtained from the Curves in Fig. 11.

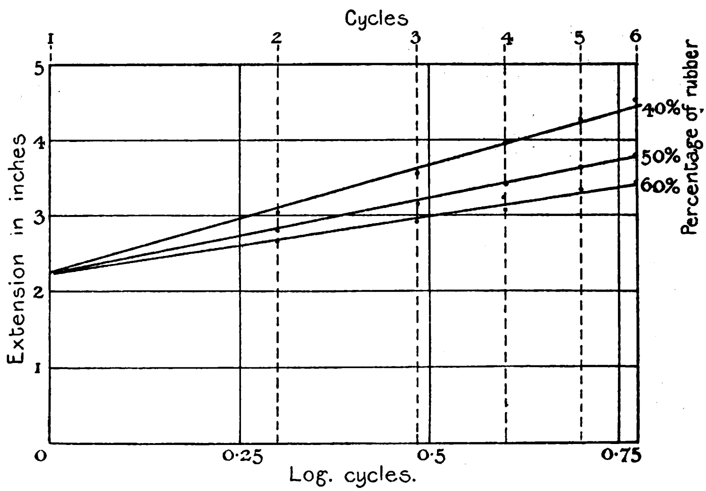


FIG. 13.—Showing that in the successive Cycle Test, with a Load-limit corresponding to a given Extension for the First Cycle, the Maximum Extension for each Cycle plotted against the Logarithms of the Numbers of the Cycles gives a Straight Line. Particulars from Fig. 11.

limit increases with each cycle, but that the rate of increase follows a logarithmic law from the second cycle onwards as the number of the cycles increases.

The time taken to draw the extension curve for each cycle is approximately the same for each cycle, and if we measure the increment of extension due to each cycle and plot these quantities against the logarithms of the number of the cycles (*i.e.*, log time, since the time for describing each cycle is constant), we shall get a straight line.

These results are shown in Fig. 13 for mixings with various percentages of rubber, the increments of extension being measured from Fig. 11.

In order to obtain a curve which is characteristic of the material, it will probably be found sufficient to put the specimen through 4 cycles only, which can be done in most cases in five or six minutes. The extension for the various cycles from the second cycle onward follows the law:—

Extension $= a + b$ log. number of cycle where a represents the extension due to the second cycle, and b the increment of extension due to the subsequent cycles. It will be seen, therefore, that the numerical values of these constants will be characteristic of the material concerned, and may be used to describe its physical quantities.

These curves are important, as they practically represent the power of recovery of the rubber in question; it is of interest to compare Fig. 13 with the results given in Fig. 16, which represents the slow stretch of these same rubbers under constant load.

17. Constant Extension Tests—Method (*e*).

In these tests the specimens are given a constant elongation by being stretched between two fixed points, arrangements being made to measure the decrease in tension at definite time intervals.

This may be done by extending the specimen vertically, and resting the top grip upon a horizontal support, and attaching a balance arm to the grip so that by adding the requisite weights to the balance pan the grip may be just raised clear of its support, thus measuring the tension. This arrangement is due to Phillips,* who found that on plotting the tension against the logarithm of the time a straight line was obtained so that the stress s obeys the law—

$$S = a + b \log t.$$

In conjunction with Mr. Philip Kemp, the author has carried out a large number of experiments at temperatures ranging from 120° to 200° F. on the diminution in tension with time in 3-in. specimens, with a constant extension of 100 per cent.

The first series of these experiments was directed to ascertaining the relative durability of specimens made from the same compound, but vulcanised at a given temperature for different lengths of time.

* *Philosophical Magazine*, vol. 9, p. 513, 1905.

The material used was specially prepared by Firm A in the form of sheet—there were two sets of sheets, one containing 88 per cent. Para and the other 66 per cent. Taking the normal times of vulcanisation

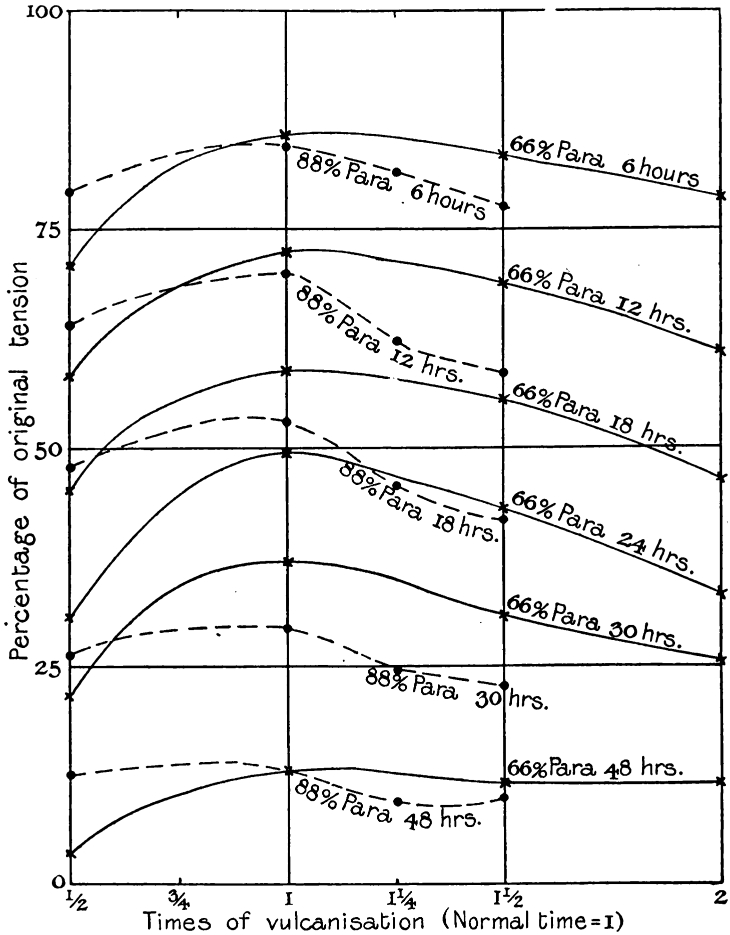


FIG. 14.—Effect of Constant Elongation of 100 per Cent. at a Temperature of 180° F. on Specimens with various Degrees of Vulcanisation for Periods of Time ranging from Six to Forty-eight Hours.

Specimens, 3 in. long, of 88 per cent. Para and 96 per cent. Para, by Firm A.

in each case as unity, the times of vulcanisation for the 66 per cent. Para sheets were : $\frac{1}{2}$, 1, $1\frac{1}{2}$, and 2 ; and for the 88 per cent. Para sheets : $\frac{1}{2}$, 1, $1\frac{1}{4}$, $1\frac{1}{2}$.

The specimens were maintained at an extension of 100 per cent. in an oven, the temperature of which was kept constant by means of a thermostat, and tests were made at 150, 160, 170, 180, and 200° F., the decrease in tension with time being measured by Phillips' method.

It was found that under these conditions the tension-time curves only approximately followed the logarithmic law.

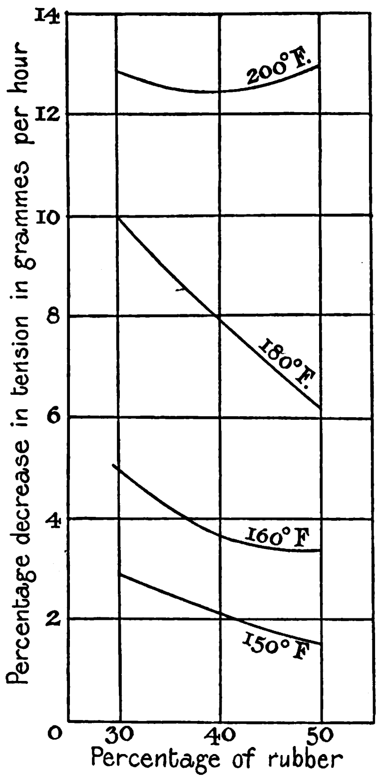


FIG. 15.—Decrease in Tension in Specimens by Firm G, containing various Percentages of Rubber when kept Extended to Twice their Original Length at Temperatures ranging from 150° F. to 200° F.

The test-pieces were 3 in. in length and the percentage decrease in tension per hour was taken from the third to the sixth hour.

On plotting the percentages of the original tension obtaining in the specimens after heating for a given number of hours at 180° F. it was found that the decrease in tension for the under-vulcanised and for the over-vulcanised specimens was in each case greater than that for the

correctly vulcanised ones. These results are shown in Fig. 14, and it will be seen that for the under-vulcanised specimens the deterioration has been less in the higher grade rubber than in the lower one, whereas for the normally vulcanised and over-vulcanised samples this position is reversed. The deterioration expressed as the percentage decrease in tension in grammes per hour taken from the third to the sixth hour with a constant extension of 100 per cent. is shown in Fig. 15 for normally vulcanised samples by Firm G containing various percentages of Para rubber, the tests being carried out at temperatures ranging from 150° F. to 200° F. It will be seen that, except at a temperature of 200° F., where the rates of deterioration are nearly the same for all the specimens, the high-grade rubbers deteriorate less rapidly than the lower grade one.

The second series of these experiments was concerned with cable coverings by various makers, but the results obtained did not place the materials in the same order of merit as that of their respective C.M.A. grades. This is possibly due to the fact that the cable coverings are made up of three distinct layers of material of different composition which have different rates of deterioration.

Experiments with specimens containing various proportions of substitute were also made with inconclusive results.

The author is reluctant to abandon what appears from its nature to be a good test, and suggests that further investigations in the hands of those who have an intimate knowledge of the ingredients and the vulcanisation treatment of the specimens, and who are in a position to vary these quantities, might lead to valuable results.

The results of experiments on the rates of decrease in tension, with a constant extension of 100 per cent. at atmospheric temperature, are given in Table II. for specimens containing 66 per cent. and 88 per cent. Para by Firm A, and vulcanised to various degrees.

A consideration of this table shows that the decrease in tension at ordinary temperatures in air differs from that at high temperatures, and that—at any rate in the month over which the experiment extended—the correctly vulcanised 66 per cent. specimen deteriorated less quickly than the under-vulcanised and more quickly than the over-vulcanised ones. With the 88 per cent. specimens, all one can say is that the under-vulcanised specimens deteriorate the most quickly. The ratios of the sub-permanent set twenty-four hours after release to the set on release seems to be a minimum for the full time of vulcanisation.

These experiments should be pursued further and continued for a longer period, as it would be of considerable interest to determine the precise relationship between the degree of vulcanisation and the decrease in tension at constant extension.

At the present time, with regard to cable coverings, considerable differences exist in the degree of vulcanisation favoured by different makers; some firms prefer slightly to under-vulcanise their cable coverings to ensure that the tinning shall remain clean and bright,

TABLE II.

Decrease in Tension with Constant Extension of 100 per Cent. at Atmospheric Temperature on 3-in. Test-pieces containing 66 per Cent. and 88 per Cent. Para by Firm A.

Time and Date.	66 per Cent. Rubber.						88 per Cent. Rubber,					
	½ Time Vulcanisation.	¾ Time Vulcanisation.	Full Time Vulcanisation.	1¼ Time Vulcanisation.	1½ Time Vulcanisation.	2 Times Vulcanisation.	½ Time Vulcanisation.	¾ Time Vulcanisation.	Full Time Vulcanisation.	1¼ Time Vulcanisation.	1½ Time Vulcanisation.	2 Times Vulcanisation.
July 21st, 11 a.m. ...	216	341	450	565	575	806	316	417	545	674	822	1,021
July 23rd, 11 a.m. ...	179	314	424	542	557	784	289	393	522	654	789	9
August 23rd, 11 a.m. ...	156	289	393	505	522	739	265	362	491	607	742	Broken
Percentage decrease in first 2 days	17·1	7·8	5·7	4·1	3·0	2·8	8·5	5·7	4·2	2·9	4·1	4·8
Percentage decrease in following 4 weeks...	12·8	8·0	7·3	6·8	6·2	5·7	8·3	8·0	6·0	7·1	5·9	—
Set on release	0·83 in.	0·46 in.	0·30 in.	0·19 in.	0·20 in.	0·14 in.	0·48 n.	0·38 in.	0·10 in.	0·18 in.	0·14 in.	—
Percentage ditto on original length ...	28	15	10	6·3	6·7	4·7	16	13	3·3	6·0	4·7	—
Set after 24 hours ...	0·43 in.	0·23 in.	0·15 in.	0·10 in.	0·15 in.	0·09 in.	0·22 in.	0·20 in.	0·03 in.	0·10 in.	0·06 in.	—
Ratio $\frac{\text{set after 24 hours}}{\text{set on release}}$	0·52	0·51	0·50	0·52	0·75	0·64	0·46	0·53	0·30	0·56	0·43	—

whilst others consider that full vulcanisation, or even a slight amount of over-vulcanisation, improves the lasting qualities of the cable.

The rates of deterioration in air and at high temperatures should be studied in order, if possible, to establish a relation between the two, so that the lengthy period required for the air-deterioration test could be avoided. The study of the deterioration at high temperatures should also yield useful results with regard to the best degree of vulcanisation for cables for India and other warm situations.

18. Constant Load Tests—Method (*d*).

The slow stretch in rubber under a constant load has been studied by several investigators, notably by Bouasse * and Phillips. † The latter worked with rubber bandages 30 cms. long, to which a scale-pan was attached ; the extensions were measured against a scale by means of a telescope. Plotting scale readings against log time, he found that a straight line was obtained. If x = the extension at a given time t from the moment of applying the load we have the relation—

$$x = a + b \log t;$$

or—

$$\frac{x - a}{\log t} = b.$$

On removing the load from the rubber it gradually returns to its original length, according to the law—

$$x = a + b \log t - (a + b \log t_0),$$

i.e.—

$$x = b \log \left(\frac{t}{t_0}\right),$$

where t is the time which has elapsed since the load was put on, and t_0 is the time since the load was removed.

The relation of the constants a and b to the stretching load were found by plotting the curves of stretching for different loads ; these show that $\frac{b}{\text{load}}$ is nearly constant, or that b is proportional to the load.

The author has employed this method in the examination of commercial rubbers, measuring the extensions by means of a cathetometer.

The standard test-pieces were loaded in each case with a 2-lb. weight, and 1 minute was allowed to elapse before the readings of

* "Sur la Réactivité du Caoutchouc Vulcanisé," par H. Bouasse et L. Carrière, *Annales de la Faculté des Sciences de Toulouse*, 2nd Series, v.

† "The Slow Stretch in Indiarubber, Glass, and Metal when Subjected to a Constant Pull," *Philosophical Magazine*, vol. 9, p. 515, 1905.

the slow stretch were taken; this is a convenient arrangement, as it gives the zero on the log time scale for the slow-stretch curve.

The extension x in a given time t is given by the equation—

$$x = a + b \log t,$$

where a is the initial extension in the first minute and b the increment of extension with time due to the slow stretch; the numerical values of these constants will therefore be characteristic of a given mixing, and may be used to describe its physical properties.

It is not necessary to take readings on retraction as well as on extension since the slow recovery on retraction is a function of the slow stretch on extension, and since the results follow a straight-line law,

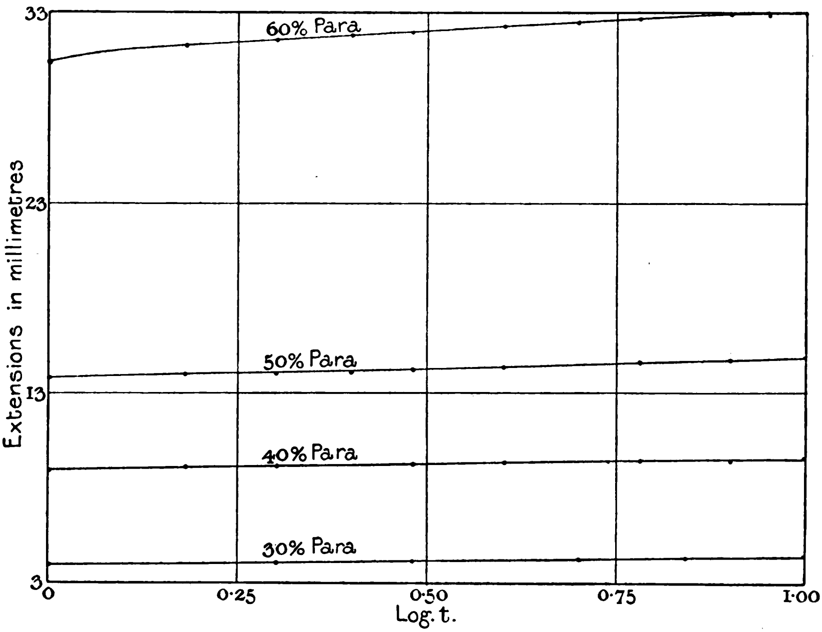


FIG. 16.—Results of Slow Stretch Test on Mixings containing various Percentages of Para by Firm G.

four or five readings will suffice at time intervals of 2 or 3 minutes, the whole test thus taking about 10 minutes.

Fig. 16 is given as an example of the way in which this test may be used to discriminate between mixings in which the rubber contents are varied. The samples were by Firm G, and contained 30, 40, 50, and 60 per cent. of rubber respectively; the values of the constants are given in Table III.

Fig. 17 is given as an example of the application of the slow-stretch test to the discrimination of the degree of vulcanisation of a given mixing. This Fig. shows the results for specimens containing 88 and 66 per cent. of Para by Firm A, with various degrees of vulcanisation ; it will be noticed that the curves for the under-vulcanised specimens lie above those for the correctly vulcanised ones, while the curves for the over-vulcanised ones lie below the normal curves. Further, the curves for the over-vulcanised specimens tend to become horizontal as

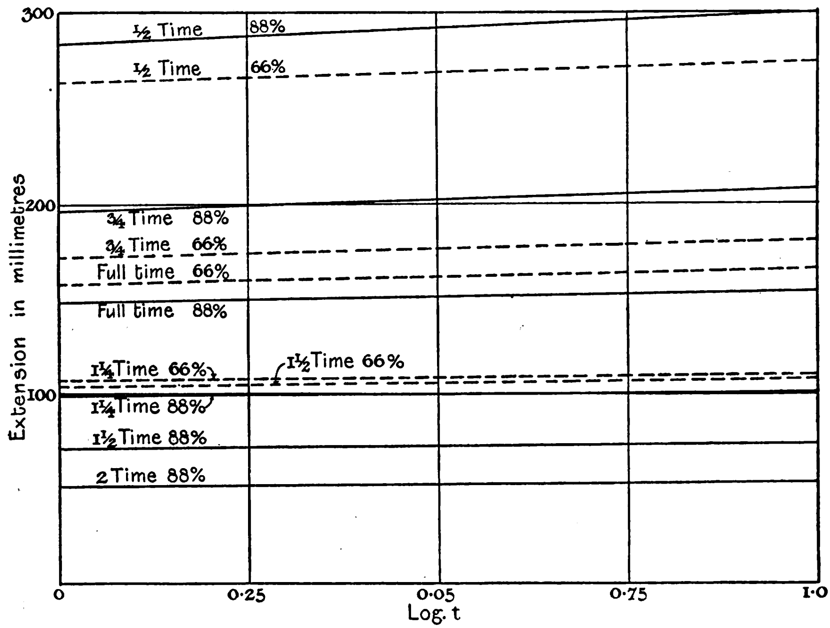


Fig. 17.—Results of Slow Stretch Test on Specimens containing 88 per Cent. and 66 per Cent. Para by Firm A, with various Degrees of Vulcanisation as Marked on the Curves, the Full Time of Vulcanisation being taken as Unity.

The full lines are the curves for 88 per cent. Para and the broken lines those for 66 per cent. Test temperature, 58° F.

the degree of vulcanisation increases, while those for the under-vulcanised ones become more and more inclined to the horizontal as the degree of vulcanisation decreases.

19. High Temperature Tests.

The author suggested in 1907* that a deterioration test at a high temperature should be used in conjunction with the hysteresis test as a measure of the probable durability of the rubber.

* *Journal of the Institution of Electrical Engineers*, vol. 39, p. 118, 1907

He has made a large number of experiments at various temperatures with a view to stating the limits within which the hysteresis loops before and after heating should lie for a given grade of rubber. With regard to cable coverings he had in mind the obtaining of samples from actual installations, the grade and age of which were known and the comparison of the hysteresis loops of such samples with those obtained from samples of similar grade by the same maker when new.

A high temperature test could then be found which would give a similar result in a reasonable time.

In spite, however, of an appeal to contractors for such samples in the electrical press he was unable to obtain any with particulars upon which he could rely, but from his experiments on the matter he has little doubt that in the hands of those who know the complete history

TABLE III.

Numerical Value of Constants a and b in Equation $x = a + b \log t$.

Mixing.	*a.*	*b.*
60 per cent. rubber ...	30·5	2·5
50 " " ...	13·8	1·0
40 " " ...	8·9	0·6
30 " " ...	4·0	0·3

of the material under consideration a satisfactory test on these lines could be obtained.

Professor Bouasse, of the University of Toulouse, who has made a valuable and exhaustive study of the physical properties of rubber from a theoretical point of view, has worked on the effect of high temperatures on rubber, and a brief *résumé* of his results on this subject is given in Appendix A as a guide to further workers in this field.

20. SUBSTITUTE.

It is possible for an expert rubber chemist to detect by chemical analysis proportions of substitute in a mixing of the order of 5 per cent., but it is doubtful if so small a quantity could be detected by either dry or moist heat tests now in vogue.

The presence of a small amount of high class oil substitute appears to improve the initial physical properties of a mixing and does not appreciably lower its insulation resistance; as to whether its durability is affected only further tests can show.

The author in conjunction with Messrs. Clayton, Beadle, and Stevens,

has made a series of experiments on a set of specimens specially made up containing given proportions of rubber and substitute, in which the rubber contents have been progressively diminished and replaced with substitute so that the amount of mineral filling remained constant throughout the series.

The particulars of the mixing are given in Table IV. :—

TABLE IV.

Reference Number.	Composition of Mixing.				Cured for 3 Hours at °C.
	Rubber.	Substitute.	Zinc Oxide.	Sulphur.	
	Per Cent.	Per Cent.			
1,379	60	0	37	3	127·5
1,381	50	10	37	3	127·5
1,382	50	10	37	3	132·0
1,389	40	20	37	3	132·0
1,390	40	20	37	3	135·5
1,391	30	30	37	3	135·5
1,392	30	30	37	3	139·0

These specimens were subjected by Dr. Stevens to the following tests :—

1. Elongation and load at rupture.
2. Measurement of the sub-permanent set after a constant extension of 400 per cent. for 24 hours: (*a*) ½ hour after release, (*b*) 6 hours after release.

The results of these tests are given in Table V. (see page 728).

At the same time the author submitted the same series of specimens to the following tests :—

1. The hysteresis test with successive cycles.
2. The slow-stretch test under constant load.

The results of these tests are shown in Table VI. (see page 730) and in Figs. 18, 19, and 20.

A consideration of Table VI. and of Fig. 19 shows that the results obtained by the hysteresis machine are more consistent than those furnished by the tests in Table V.; they are, moreover, obtainable in a much shorter space of time.

21. Quality of Rubber.

In order to see if the hysteresis machine could discriminate between various brands of rubber when employed in a mixing with as much as 70 per cent. of mineral filling, a series of experiments were made with specimens prepared by Firm G, containing respectively 30 per cent. of

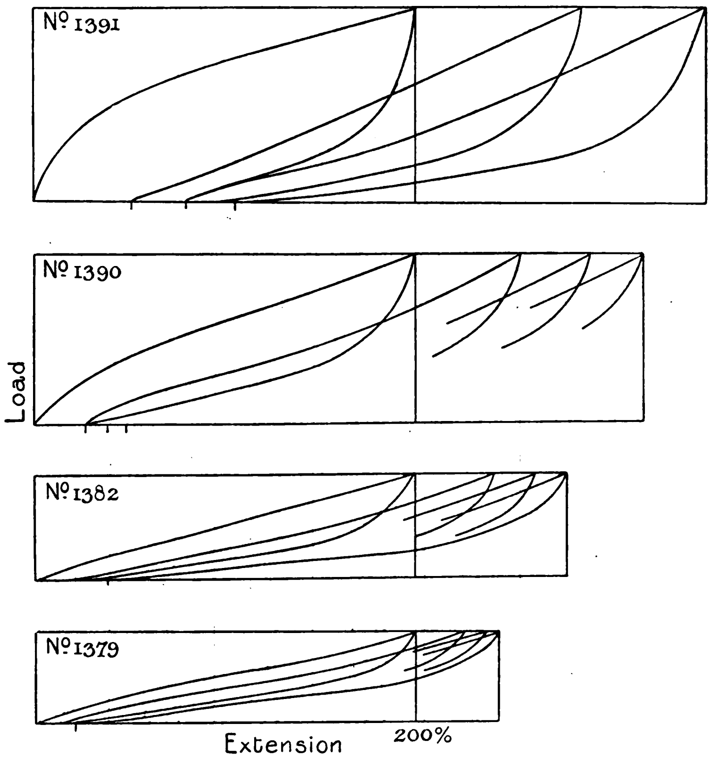


Fig. 18.—Results of Hysteresis Test with successive Cycles on Specimens containing various Proportions of Substitute.

Reference No.		Rubber, per Cent.		Substitute, per Cent.		Cured for 3 Hours at °C.
1379	...	60	...	0	...	127·5
1382	...	50	...	10	...	132·0
1390	...	40	...	20	...	135·5
1391	...	30	...	30	...	135·5

Specimens, 3 in. × ½ in. Room temperature, 59° F.

Para, cultivated Para, Lanadron, Cameta, and Para Negroheads, the balance being mineral in each case.

These specimens were vulcanised under identical conditions and were submitted to the hysteresis test with successive cycles. Some of

the specimens appeared to be slightly faulty, due to the formation of small blow-holes in them during vulcanisation.

The results are shown graphically in Fig. 21, in which the maximum extensions for the various cycles and the sub-permanent set remaining on the completion of the cycles are plotted against the logarithm of the number of the cycles. It will be seen that a straight-line law obtains in each case from the second cycle onwards over the range shown.

It will be noticed that the results due to the maximum extension per cycle, and those due to the sub-permanent set per cycle do not place the materials in the same order of merit.

TABLE V.

Effect of Substitute.

Results of tests on elongation at rupture, breaking load, and percentage recovery after stretching to four times original length for 24 hours. Specimens, 3 in. long, ½ in. wide.

Reference Number.	Rubber.	Substitute.	Elongation at Rupture.	Breaking Load. Grammes per Square Millimetre.	Percentage Recovery Time after Release when Measured.	
					½ Hour.	6 Hours.
	Per Cent.	Per Cent.	Per Cent.			
1,379	60	—	9·78	314	88·9	93·7
1,381	50	10	10·00	287	84·1	91·9
1,382	50	10	9·64	362	87·2	93·6
1,389	40	20	9·50	282	85·0	93·5
1,390	40	20	9·50	358	79·3	89·4
1,391	30	30	8·58	271	63·9	81·6
1,392	30	30	6·70	238	Broke	Broke

The author has found, however, in cases in which he has known the actual order of merit of the samples from a knowledge of their composition, that the results of the maximum extensions per cycle have placed the specimens in their correct order, whereas the results for the sub-permanent set have not done so. Further, the maximum extensions are far easier to measure than the sub-permanent set, as the quantities are larger and the specimen is under a constant tension at the time the quantity is recorded.

The sub-permanent set is difficult to measure, since the retraction of the specimen is very rapid as zero load is approached.

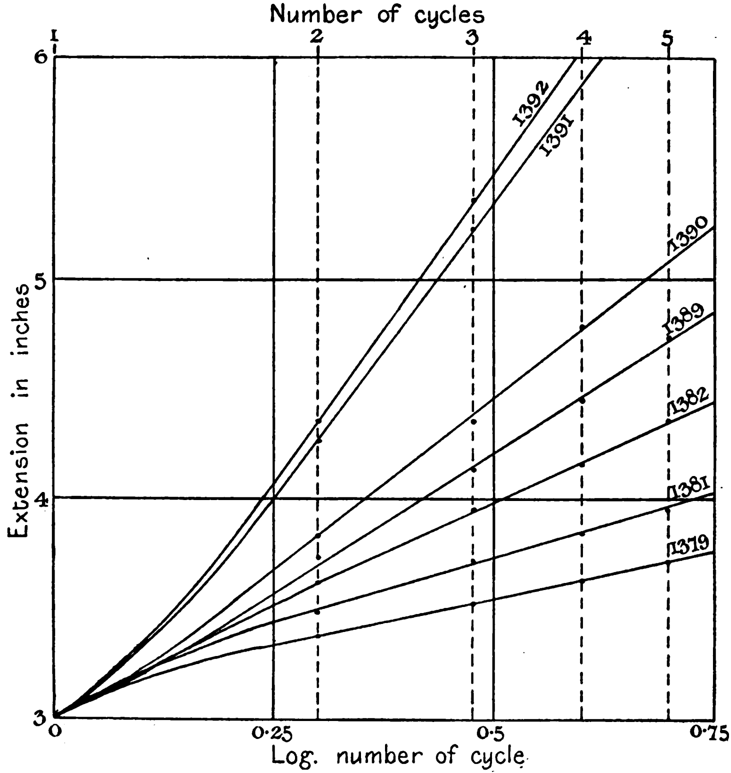


FIG. 19.—Result of Hysteresis Test with successive Cycles on Specimens containing various Proportions of Substitute.

Reference No.		Rubber, per Cent.		Substitute, per Cent.		Cured for 3 Hours at °C.
1379	...	60	...	0	...	127·5
1381	...	50	...	10	...	127·5
1382	...	50	...	10	...	132·0
1389	...	40	...	20	...	132·0
1390	...	40	...	20	...	135·5
1391	...	30	...	30	...	135 5
1392	...	30	...	30	...	139·0

The maximum extension for each cycle are plotted against the logarithm of the number of the cycle.
Specimens, 3 in. × ½ in.
Room temperature, 59° F.
The quantities are obtained from the diagrams in Fig. 18 and their numerical values are given in Table VI.

22. Suggested Lines for Test of Standard Material.

In this country, owing to the initiative of the Cable Makers' Association, we are fortunate in possessing a partial system of standardisation for rubber cable coverings.

The standardisation, however, only extends to certain particulars, thus for each size of cable the minimum thickness of dielectric is fixed, and certain grades or quantities are established, the minimum insulation per mile being fixed for each of these grades.

It will be seen, therefore, that the individual manufacturers have a free hand as to the ingredients they employ in the compounds, provided that the finished article complies with the above conditions.

It is suggested that a further standardisation, based on the physical

Table VI.

Effect of Substitute.

Results of tests with the hysteresis machine.

Test-pieces, 3 in. × ½ in., with an extension limit to the first cycle of 200 per cent.

Temperature, 58° F.

Reference Number.	Rubber.	Substitute.	Area of First Loop in Square Inches.	Maximum Extensions in Inches.			
				1st Cycle.	2nd Cycle.	3rd Cycle.	4th Cycle.
	Per Cent.	Per Cent.					
1,379	60	—	0·46	3·00	3·38	3·53	3·64
1,381	50	10	0·53	3·00	3·48	3·72	3·85
1,382	50	10	0·74	3·00	3·62	3·95	4·16
1,389	40	20	0·95	3·00	3·74	4·13	4·46
1,390	40	20	1·42	3·00	3·83	4·35	4·75
1,391	30	30	2·37	3·00	4·26	5·22	—
1,392	30	30	3·37	3·00	4·35	5·36	—

properties of the rubber, may prove advantageous in discriminating between C.M.A. material and other material on the market which is sold as being "equal to C.M.A."

Such a test would also enable the manufacturers to secure uniformity in the degree of vulcanisation, in the quality of the rubber employed, and in the amount of mineral filling used.

In order to form an opinion as to the feasibility of the above suggestions let us first examine the results obtained from C.M.A. cables by leading firms in this country, with a view to seeing the amount of uniformity in their physical properties which the C.M.A. limits as to insulation resistance and thickness of dielectric have already secured.

The author was kindly provided by six leading firms with samples of coverings stripped from $\frac{19}{16}$ cable in 2,500- and 600-megohm C.M.A. grades, and in some cases with 1,000, 600, and 300 non-association grades. When first submitted to him, and therefore probably freshly manufactured, the 2,500-megohm grade samples all extended over 300 per cent. before breaking, while for the 600-megohm C.M.A. grade the extensions at breaking lay between 200 per cent. and 300 per cent., with the exception of one sample, which extended 305 per cent. before

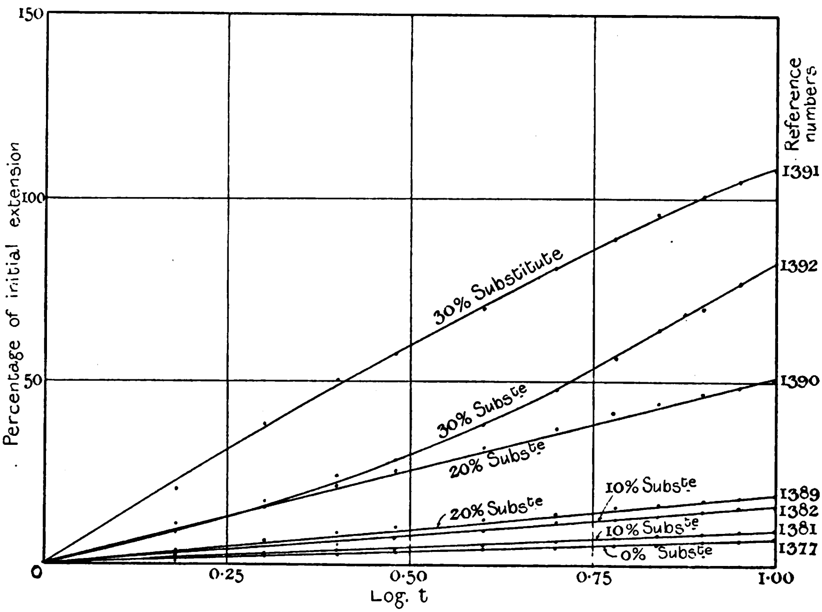


FIG. 20.—Effect of Slow Stretch Test on Specimens with various Proportions of Substitute.

A 2-lb. weight is hung from the test-piece, and after one minute has elapsed the slow stretch with time is noted. This stretch expressed as a percentage of the initial extension in one minute is here plotted against the logarithm of the time.

rupture. The non-association cables, with one exception, broke with extensions of from 80 per cent. to 200 per cent.

These samples were exposed to the air for three months, and as the rubber covering was stripped from the core, both the inside and outside were exposed, and the samples deteriorated to some extent; and to allow for this the extension limits decided upon for the tests were 200 per cent. for the 2,500-megohm grade, and 150 per cent. for the 600-megohm grade.

Fig. 22 A shows superposed the hysteresis loops for 600-megohm

C.M.A. cable coverings by six leading firms, the extension limit being 150 per cent.

Fig. 22 B shows similar curves for the non-association cables by those of the above firms who make for the non-association class.

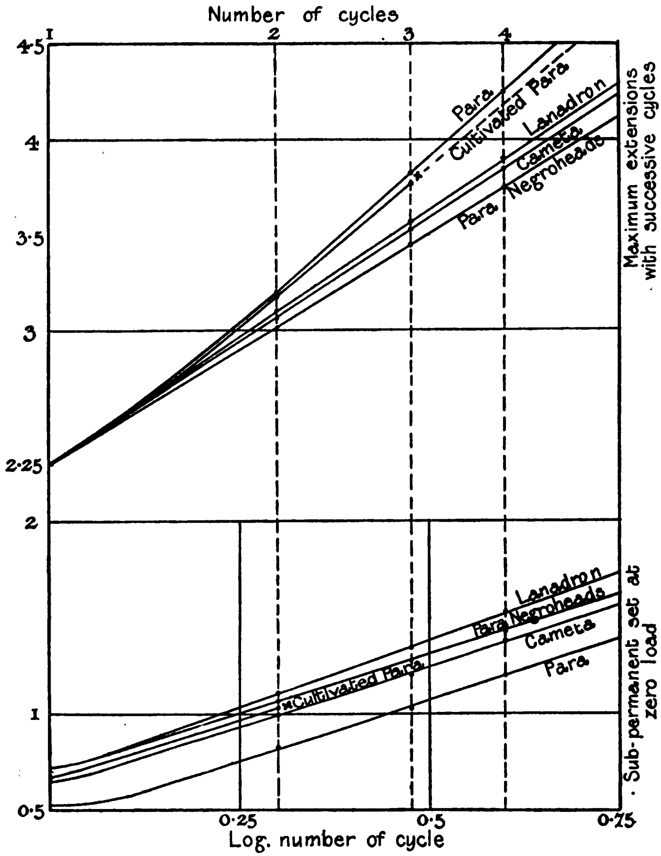


FIG. 21.—Maximum Extensions for successive Cycles plotted against the Logarithm of the Numbers of the Cycles, together with the Sub-permanent Set remaining on the Completion of the Cycle plotted in the same Way, for various Brands of Rubber.

The proportion of rubber in each of the mixings was 30 per cent., the balance being mineral.

It will be seen that with one exception the non-association coverings have failed to reach the 600-megohm C.M.A. limit.

Fig. 22 C shows in a similar manner the hysteresis loops for 2,500-megohm coverings, with an extension limit of 200 per cent., while

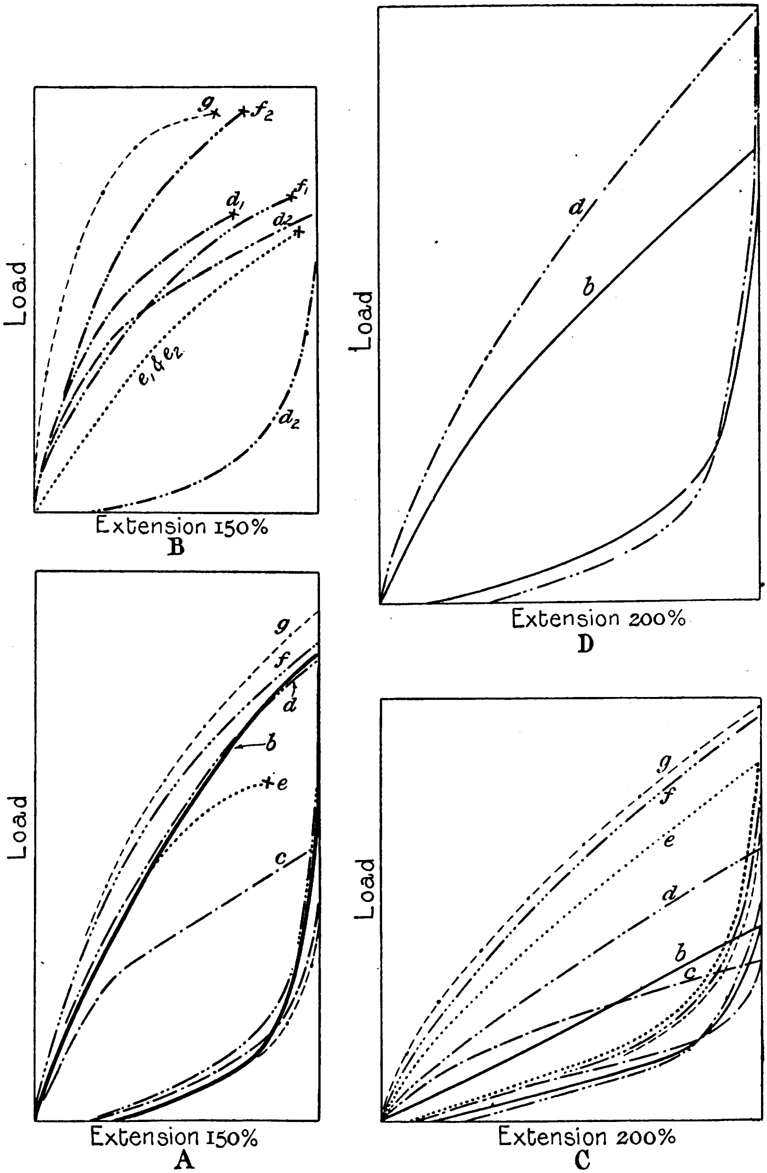


FIG. 22.—Results of Single Hysteresis Loop Test on $\frac{19}{16}$ Cable Coverings by six C.M.A. Firms in 2,500- and 600-Megohm C.M.A. Grades and in the Non-association Class.

b = Firm B ————
c = Firm C ——.——
d = Firm D ——..——
e = Firm E ....
f = Firm F ——...——
g = Firm G - - - - . - -

A = 600 megohm C.M.A.
B = Non-association.
d_1 = 300 megohm, Firm D.
d_2 = 600 megohm, Firm D.
e_1 and e_2 = 600 and 300 megohm, Firm E.
f_1 and f_2 = 600 and 300 megohm, Firm F.
g = 600 megohm, Firm G.

C = 2,500 megohm C.M.A.
D = 600 megohm C.M.A. with 200 per cent. extension limit.

Fig. 22 C shows the result of putting the 600-megohm C.M.A. coverings to the higher grade test with a 200 per cent. extension.

All the 600-megohm C.M.A. coverings shown in Fig. 22 A broke before reaching the 200 per cent. extension, with the exception of *b* and *d*, and it will be seen that the loops for these two specimens as shown in Fig. 22 C are larger than those for the 2,500-megohm grade in Fig. 22 B.

It is evident, therefore, that the existing C.M.A. conditions have already brought about results which allow of the two grades of cable coverings being broadly distinguished from one another by means of their physical properties.

It must be remembered that the results shown in Fig. 22 are for material supplied by makers of repute, and that most of the cheap inferior material on the market can make no serious attempt at complying with the tests outlined above.

It is not suggested that the single hysteresis loop would by itself furnish a reliable test, but it is urged that the electrical tests for capacity and insulation resistance should be supplemented by suitable physical tests, since it is upon the physical properties of a compound that the permanence of its electrical qualities will depend.

It is suggested that systematic experimenting by those interested in cable manufacture or in rubber testing, and the comparison of results over a year or two, should lead to the formulation of reliable physical tests.

The points which a satisfactory physical test should ensure would seem to be the following :—

(*a*) The employment in the mixing of a given percentage of rubber of a quality that shall not fall below a given standard.
(*b*) The restriction of the employment of recovered rubber and substitute within limits as to both quantity and quality.
(*c*) The degree of vulcanisation imparted.
(*d*) The character of the mineral filling used.

It would appear hopeless to expect any one test to fill all the above requirements, but the author thinks that possibly the necessary tests might be carried out with the hysteresis machine on the following lines :—

1. The hysteresis loop for a given grade of covering to lie within certain limits as to load, extension, and area.
2. The hysteresis loop after the specimen has been heated under specified conditions as to time and temperature should not vary from the loop under (1) by more than a specified amount.
3. The increments of extension for successive cycles to fall within specified limits.

The formulation of a satisfactory test for rubber lies with those who are intimately concerned with the rubber industry, and the author can only venture to hope that the hysteresis machine and the experimental results he has obtained with it may prove of some assistance to them in their researches.

The author wishes to express his thanks to the following gentlemen: To the Principal and Committee of the School of Technology, Manchester, for facilities afforded for the construction of the apparatus and the carrying out of the experiments. To Mr. Philip Kemp and Mr. J. Urmston for assistance in the experimental work. To Messrs. J. Connolly, H. Blick, J. Bowyer, Professor T. W. Fox, and Dr. H. P. Stevens for suggestions and advice. To Messrs. The Anchor Cable Company; British Insulated and Helsby Company; Clayton Beadle & Stevens; Connolly Brothers; Henleys; David Moseley & Sons; and the Silvertown Company for materials supplied. To Messrs. P. Bamford, J. Bleakley, H. N. Cunliffe, C. W. Gamble, A. Priestley, F. Parry, and G. P. Willoughby for assistance at various times.

APPENDIX A.

High Temperature Tests.

The following results of high temperature tests have been obtained by Professor Bouasse * of Toulouse. He used in his experiments rubber cord 4 mm. diameter and from 15 to 30 cms. in length, containing rubber and sulphur only. The specimen was suspended vertically, and carried on its lower end a scale-pan which was loaded by means of a copper chain weighing 50 grammes per metre, which was fed into and withdrawn from the pan at a given rate. The extensions were read to one-tenth of a millimetre by means of a telescope reading on to a light wooden scale attached to the lower end of the specimen, the load being read at the same time from marked tabs on the copper chain; the traction curves were afterwards plotted in the usual way.

1. In order to study the variation in elasticity with temperature, specimens were placed in an oven at 248° F. for 15 minutes, and loads were applied and withdrawn at regular intervals, the amplitudes of the extensions being noted and compared with those obtained from similar specimens at normal temperature.

If $P =$ load in grammes and $R = \dfrac{\text{extension hot}}{\text{extension cold}}$, the diminution in elasticity at high temperature is shown by the following results:—

P	R
100	1·28
200	1·54
300	2·00

* Bouasse, *loc. cit.*

2. *Effect of Heating at* 300° *F.*—In the following experiments the specimens were first brought to an approximately constant condition by putting them through 5 cycles of extension and retraction with a given load limit at normal temperature, they were then placed in an oven at 298° F., and after removal from the oven were again put through 5 cycles with the same load limit as before.

If l and l_1 are the amplitudes of the last cycles of these two series, we have :—

TIME OF HEATING.

	0 hr. 5 min.	1 hr.	2 hr.	4 hr.	23 hr.
$(l_1-l):l$ ...	0·36	0·09	—0·26	—0·57	—0·81

The rubber becomes increasingly black with time and the surface hardens; at the end of the test the cord was cracked and fragile.

3. *Influence of Lapse of Time after Removal from the Oven.*—Oven temperature, 300° F.; specimens prepared as in (2); time of heating, 30 minutes.

LAPSE OF TIME AFTER REMOVAL FROM THE OVEN.

	0 hr.	0 hr. 5 min.	1 hr.	2 hr.	24 hr.	48 hr.
$(l_1-l):l$	0·35	0·33	0·13	0·27	0·08	0·08

The heating effect is therefore not permanent but is subject to a subsequent change which continues for some hours.

4. *Influence of the Amplitude of the Cycle on the Effect of Heating.*—Time of heating, 32 minutes; specimen placed in the oven 3 minutes after removal from the testing-machine, and allowed to cool for 57 minutes before the second test; other conditions as in (3).

LOAD LIMITS OF CYCLES IN GRAMMES.

	50	150	250	500	800	1,000
$(l_1-l):l$	0·39	0·33	0·28	0·19	0·03	0·03

The relative extension per cycle diminishes in proportion as the amplitude increases; the loops are flatter after heating than before and they also enclose a smaller area.

Effect of Heating at 212° *F.*—At this temperature the sulphur does not melt, and the alteration in the rubber is less extensive and slower than at 300° F.

5. *Effect of Time of Heating.*—Preparation as in (2).

TIME OF HEATING.

	0 hr.	5 min.	1 hr.	2 hr.	4 hr.
$(l_1-l):l$		0·31	0·34	0·41	0·52

6. *Influence of Lapse of Time after Removal from the Oven.*—Preparation as in (2); the second series of cycles being fixed at the following times after removal from the oven :—

LAPSE OF TIME AFTER REMOVAL FROM THE OVEN.

	0 hr.	0 hr. 5 min.	1 hr.	2 hr.	4 hr.	24 hr.
$(l_1-l):l$ ...	0·33	0·27	0·23	0·13	0·07	0·07

7. *Influence of the amplitude of the Cycle on the Effect of Heating.*—Preparation as in (2); heated for 30 minutes and cooled for 65 minutes after leaving the oven for the second series of cycles.

LOAD LIMIT OF CYCLES IN GRAMMES.

	50	150	250	500	800	1,000
$(l_1-l):l$ ...	...0·34	0·23	0·22	0·16	0·12	0·11

The results differ from those at 300° F. in that the loops are less flat after heating than before; in other words, the maximum difference in the abscissæ for a given load is greater after heating than before heating.

Effect of Heating at 138° *F.*—It is generally assumed that rubber may be heated to 176° F. without change, but the following experiments show that this view is erroneous.

8. *Influence of the Time of Heating.*—Preparation as in (2).

TIME OF HEATING.

	30 min.	1 hr.	2 hr.	4 hr.	24 hr.	51 hr.	96 hr.
$(l_1-l):l$ ...	0·17	0·20	0·20	0·20	0·15	0·10	0·03

9. *Influence of Lapse of Time after Removal from the Oven.*—Preparation as in (2). The following table includes the variation in the thickness of the loop—that is to say, the maximum difference in the abscissæ for a given load (e_1-e):—

LAPSE OF TIME AFTER REMOVAL FROM THE OVEN.

	0 hr.	1 hr.	4 hr.	25 hr.	50 hr.
$(l_1-l):l$	0·17	0·15	0·12	0·09	0·08
$(e_1-e):e$	0·29	0·20	0·25	0·13	0·13

10. *Influence of the Amplitude of the Cycle.*—Preparation as in (2).

LOAD LIMIT OF CYCLE IN GRAMMES.

	50	150	250	500	800	1,000
$(l_1-l):l$ ...	0·13	0·11	0·10	0·09	0·08	0·07

Effect of Cooling in Solid CO_2.—A similar series of experiments to the above was carried out on two sets of specimens, one of which was tested at normal temperature while the other was cooled in carbonic acid snow for 45 minutes; the cooling was found to have had no effect on the rubber.

DISCUSSION.

Mr. Whalley.

Mr. A. WHALLEY: Cutting with a knife the strips to be tested is the best manner of preparation in the author's experience. I think cable makers will want to compare the results thus obtained with those they get by testing the cable rubber as a complete tube before accepting this conclusion. In the past cutting with a knife has certainly caused a lot of irregular results. The strips from the same sample vary in thickness. The test on the complete tube gives an average result at once. A large number of the tests recorded deal with 88 per cent. mixture, but a comparatively small amount of this is used in cable work, though no doubt suitable for the mechanical rubber trades. One reason that a lower percentage of rubber is necessary for uniformity of electrical results at a reasonable cost is that it is difficult on mixing rolls to get a really homogeneous mixture with much above 50 per cent. of rubber. To produce a more homogeneous mixture with the higher percentages the two mixing rolls are driven at different speeds, but the increased friction causes partial vulcanisation on the rolls when the sulphur has been added. Even when the electrical results are better with the higher percentages of rubber—and in some directions they may be worse—they are not often proportional to the increased cost. I cannot but contrast the rapid conductivity of heat reported—viz., 10 to 15 minutes—with the caution in the paper not to test rubber by stretching unless it is 10 days old. As showing the need of caution in that respect, cable makers sometimes in the early days, when they were learning their experience, were tempted to strain vulcanised cables immediately after curing. Although the core then stood up to a test of 10,000 volts after it was finished, not infrequently it would break down on repetitions of the test. In Fig. 12 apparently the 50 per cent. retractive curve is missing. As regards Figs. 13 and 16, both relate to the same mixtures, and illustrate the formula $x = a + b \log$ "t," though in Fig. 13 "t" refers to cycles, and in Fig. 16 to minutes. Apparently, in Fig. 13, it is because the load is greatest on the 40 per cent. mixture that the increment of extension after the second cycle is greater than for the other mixtures, while in Fig. 16, because the load is the same for all mixtures, the greatest extension is with the 60 per cent. mixture. Of the results in Fig. 14 we have an interpretation on page 720 which should perhaps be reversed, and in connection with Fig. 15 the vertical scale is expressed as "extension" in two terms, as a percentage and also as grammes per hour. Table II. shows apparently an advantage in over-vulcanisation when the particular samples are tested under constant extension at atmospheric temperatures. I am inclined to think from the curves shown, however, that the "constant load" tests must tend to give imperfect results. If we have the same size cable dielectric in five or six qualities, it does not appear right to put the same load on each one. There must surely be some particular load which is best suited for each quality of rubber to give a test which is fair to each quality. For

example, in Fig. 20 such tests are given for those mixtures which contained substitutes, but the order and relative position of the samples is not the same as Fig. 19, where the same samples are tested for the hysteresis loop. The point I was looking into in connection with Fig. 20 was the best vulcanising temperature. For each percentage of substitute two samples were taken, and they were vulcanised at two different temperatures, apparently with the object of finding out which was the best, but no reason is given for increasing the vulcanising temperature as the percentage of rubber decreases. Table V., which amplifies the result obtained in testing the substitute mixtures, is interesting in showing that there are certain percentages which give a mixture which is mechanically stronger, when new, than one without substitute. All the tests in the paper are strictly mechanical, and none of them electrical, as pointed out by the author, who acknowledges that the testing of rubber is a very big subject. The assumption, however, that the smaller the area of the mechanical hysteresis loop the better the cable or the longer its life needs most careful examination before acceptance. Mr. Whalley.

Communicated: At first sight it might appear simpler to specify the maximum area of the loops for standard mixtures, but from the facts set forth in the paper the area of the loop appears to be directly affected, more or less, by each of the following: Length and section of sample; speed at which the loop is drawn, the effect of speed depending on the percentage of rubber; ratio of linear surface (exposed to the steam during vulcanisation) to cross-section; a vulcanisation coefficient dependent on time and temperature; previous history of sample, as affected by temperature, sunlight, ozone, chemicals, and handling; age of sample. The area of the loop appears also to be affected inversely by: Actual temperature of sample at moment of test, and perhaps for some time previous; the presence of a longitudinal joint; the percentage of rubber in the mixture. In addition to the above, each grade of raw rubber, and different parcels of the same grade, may have peculiarities which affect the area. The machine being primarily offered for testing cable samples, by cutting strips out of the tube of dielectric, the area of the loop for all the strips cut out of the same tube will not be the same unless all have the same thickness; this is very seldom the case. It would from the above, therefore, be difficult to standardise the areas of loops for particular mixtures, and the ratio of length to average width of loop for a particular percentage extension may have to be specified. Professor Schwartz's machine should be invaluable in many directions. He has made the subject of hysteresis loops of rubber one peculiarly his own.

Mr. C. J. BEAVER: The field of application of the author's hysteresis machine is an exceedingly wide one. It is, in fact, capable of much wider application in other branches of the rubber manufacturing industry than in the electrical branch. Its advantage as applied to electrical rubber work is, that it supplements other cable tests in a simple, definite, and therefore very valuable way. It is all the more Mr. Beaver.

Mr. Beaver. valuable because of the large amount of work which the author has expended in the perfecting of his machine, and in demonstrating with characteristic completeness such points as constancy of results, the effect of successive cycles of extension and retraction on various grades of rubber, methods of comparison, and the magnitude of possible errors in manipulation. Although I am not prepared to agree that physical tests can displace the usual cable tests, or that their results may be taken as a criterion of electrical efficiency or chemical stability, I think the author's development of the machine and researches in connection with it have rendered it quite ready for its application or dovetailing into existing tests used in connection with rubber cable work. For instance, as I have previously pointed out,* the durability of rubber is largely dependent on the coefficient of vulcanisation; in fact, if it could be determined as simply as the author's hysteresis loops, I would prefer it as a supplementary test. For electrical reasons, however, the value of this coefficient corresponding to the point of maximum efficiency cannot be attained on all grades of electrical rubbers, and the cable-maker's problem, therefore, is to balance all the factors in a given case to obtain the best all-round results. The ideal conditions would be to standardise a hysteresis loop for a given grade of insulation, which would coincide with the maximum combined efficiency of electrical and vulcanisation results. The maker would then have: (1) His correct electrical standard; (2) his corresponding maximum of chemical stability; (3) the corresponding physical test. When these are properly proportioned to one another for any given class of work, the author's machine will be applied to its greatest advantage, and will be of equal service to manufacturer and purchaser. Under the heading of rubber cutting, the author draws a distinction between high-grade rubbers and cable coverings, and from his supplementary remarks I gather that the passage referred to was written intentionally. I would point out that in most British makes of cable the proportion of rubber varies from about 33 per cent. in the lowest grades of insulation to 60 per cent. or so in the highest, and that in other branches of the rubber industry compound rubbers containing such percentages would not by any means be regarded as low grade. 600-megohm grade cable also called forth some rather disparaging remarks, but I really must protest that 600-megohm grade C.M.A. cable is an extremely serviceable cable which has stood the test of time, and that, regarded as rubber goods, the ordinary standard cable insulation rubbers do not call for the distinctions and comparisons made by the author. With regard to the transmission of heat determination in Table I., I would point out that this must not be taken to bear any relation to the dissipation of heat from a cable which has been warmed by overloading, as this depends entirely on the character, mass, and closeness of contact of surrounding material with the exterior surface of the cable. In further connection with this matter of quality of rubber, I would point out that Section 20, on "Substitute," has practically no

* *Journal of the Institution of Electrical Engineers*, vol. 39, p. 114, 1907.

Mr. Beaver.

connection with cable work—at least, so far as cables made in this country are concerned. Even foreign cables do not often contain more than 10 per cent. The use of recovered rubber, which is referred to at the end of the paper, is also practically unknown in cable manufacture in this country, although it is by no means a rarity in Continental or American cables. With regard to Fig. 11, illustrating the effect of successive cycles of extension and retraction, I notice the marked difference between the first and the succeeding loops. This difference appears to be due to something in the molecular structure of the rubber, which, even when stretched in the hands, is perceptibly altered by the initial stretching, probably due to the heat generated in stretching it. In newly vulcanised rubber this is sufficiently marked to cause an apparent indication of tensile weakness. This effect appears in many stages and branches of rubber manufacture, and in connection with some works operations I have taken advantage of the phenomenon to improve the tensile strength of articles in course of manufacture, so as to fit them for the mechanical requirements of the next process in the manufacture. I am interested in the curves showing Fig. 21, comparing the maximum extensions of rubber compounds made with various raw rubbers as a basis. They coincide with my experience that cultivated Para rubbers (Lanadron coming, of course, under this description) are slightly physically inferior to hard fine Para. The relative closeness of Cameta and Negroheads to hard fine Para in the diagram rather tends to confirm my view that the physical tests are not necessarily a criterion of electrical efficiency or durability, because neither of these two rubbers are particularly good in these latter respects. Of the two I should give the preference to Negroheads. I make due allowance for the fact that the comparatively low proportion of rubber in these compounds (30 per cent.) will tend to bring all the results fairly close together, but their relative positions in the diagram are undoubtedly approximately correct. Incidentally I may mention that it is exceedingly difficult to distinguish Cameta from Para by chemical tests, and this fact lends still further confirmation to my view above referred to.

Mr. Brooking.

Mr. J. H. C. Brooking: It would be very convenient to cable makers to have a machine like the one before us, but of a more portable design, to demonstrate *in situ* the advantages of their wares. I have seen machines like it before, but they have usually been of the horizontal type instead of the vertical, and occasionally they demonstrated what they were not desired to show, but the test that most people use is with the fingers, *i.e.*, to take up competing strips of rubber about 2 in. long, and gradually stretch them until one goes. I have heard that there are various methods of making one go before the other. As Professor Schwartz seems to have more facilities for making testing devices than most cable makers, perhaps he will devise a machine of that kind, and make English cable men still more indebted to him. Mr. Beaver and Mr. Whalley mentioned that there are many more testing requirements than this necessary to the cable

Mr. Brooking.

designer, the cable user, and possibly the cable seller. One of the most important of these, I think, would be the effect of heat upon cable, but for ordinary purposes, I agree that the stretch test, as shown by Professor Schwartz, should be of considerable interest to those concerned.

Mr. Cramp.

Mr. W. CRAMP: The machine which Professor Schwartz shows us to-night is so different from that which was arranged with the water balances that it forms a proof of the amount of time and ingenuity that must have been spent in reducing to such a simple form a machine originally so cumbrous. I do not understand why diagrams which are called hysteresis loops are plotted with the loads as ordinates. In electrical work we are accustomed to plot the magnetising force (which in this case corresponds to the load) horizontally, and turning the curve round gives it a curious and unfamiliar look. I notice that by Stévart's law, as stated on page 712, for a given extension, the load is proportional to the area of the cross-section of the specimen. Professor Schwartz states that he has discovered another law, which is to the effect that with constant cross-section the area of the hysteresis loop for a given load is proportional to the length of the specimen. I do not find in the paper any proof of this law, but I would suggest that an easy test of its validity is obtainable; since, if it be true, successive strips of the same cross-section with the same load should extend in proportion to their length. This is an easy test to make, and, if confirmed, it would follow that two mechanical characteristics of rubber may be expressed in the form of ergs per cubic centimetre per cycle exactly as is the case with iron hysteresis. By testing a number of specimens, different hysteretic constants might be deduced to be adopted as standards in specifications. Professor Schwartz has given some account of experiments involving time, but he does not say what effect ageing of the rubber for days or weeks will have upon the hysteresis loop. If a distinct connection can be shown between the hysteresis loop and the dielectric strength, the testing machine will be of still greater use to electrical engineers. Already it is apparent that it is of use for discovering whether what is sold as rubber is rubber; but it might also show which rubber substitutes are effective as insulators. It is not at all impossible that there may be a close connection between mechanical and dielectric strength. I note that on page 696 "the author wishes to place the machine entirely at the service of the industry without any restriction," and I should like to know whether this means that any one is at liberty to make it.

Mr. Urmston.

Mr. J. URMSTON: During the last few months I have had opportunities of carrying out a few experiments on this machine, and I find it is extremely delicate and works very well. With regard to the effect of altering the width of the sample strip under test, referred to by one of the speakers, I might remark that the same logarithmic law has been obtained for the same class of rubber for strips of different widths, so that it would seem that for any given class of rubber the same logarithmic law would be obtained irrespective of the area

of the sample, provided that the same percentage stretch were given. Mr. Urmston.

Mr. A. C. CORMACK: I should like to make a suggestion with reference to the difficulty of obtaining identical samples from cables of different size. Instead of adopting standard lengths and breadths of samples differing in thickness, it might be better to work on the law formulated by the late Professor James Thompson and Professor Barr, to the effect that, irrespective of size, "test-pieces having similar forms will give similar results if of like material." Instead of a longitudinal section, an entire tubular length of the insulation of the cable or wire could be taken. Samples from different sizes of cables would be of varying lengths, but the ratio of length to diameter could be kept constant. Such samples would not be similar, inasmuch as the ratio of thickness of envelope to diameter would not be the same for all sizes. This would not be so serious as in the case of the present specimens, and it could be got over by having two sets of specimens, one set in which the ratio of length to external diameter was equal in all specimens, and the other in which the ratio of length to internal diameter was equal in all specimens. The mean test of the two samples would be taken. In dealing with such an elastic material as rubber, the end effects of the samples will be important, and if it was arranged that similar lengths be gripped by the clamps, discrepancies from this source could be eliminated. The samples would be subjected to loads proportional to their areas. Mr. Cormack.

Professor E. W. MARCHANT: I should like to ask Professor Schwartz whether he has ever made any tests on the rate at which the electric current, through rubber, diminishes when a steady potential difference is applied, and whether that has any relation with the hysteresis loops which we have seen. Every one knows the polarisation effect with insulating materials such as rubber, and it has occurred to me that tests on this phenomenon might give some indication of the quality of rubber, and possibly of its durability. A cable maker came to me some years ago and told me of some new rubber he had tried; I believe it came from Ceylon. This rubber had appeared to him, as far as its general character went and its colour, to be quite a good rubber, but he found that on a cable it was no use at all. That leads me to think that although these extension tests may be very useful, they are not quite adequate to determine the true quality of rubber for electrical purposes. Professor Marchant.

Mr. C. F. SMITH: I think the author is unduly modest in restricting the use of his machine to the testing of rubber for electrical work. The tests that he suggests are almost purely mechanical ones, and I do not see why the same tests could not be applied to the inferior kinds of rubber used for many other commercial purposes, such as cycle tyres, etc. Another point that occurs to me is that rubber of a given composition appears to have very variable mechanical properties under certain conditions. For instance, if a piece of rubber is allowed to lie exposed to the air for some time it becomes very brittle Mr. Smith.

Mr. Smith. and inelastic. By immersion in hot water, or by carefully manipulating it, its elasticity and pliability are restored. How would the author be able to discriminate between samples which had lost their elasticity through exposure and those whose want of elasticity was due to defects of composition? Would not some definite process of preparation of the samples before testing be necessary, in order that they might start level? I also wish to ask Professor Schwartz the reason for the inversion of the axis of the hysteresis curves to which Mr. Cramp has alluded. The hysteresis loop, as we have learnt to know it, has a magnetising force plotted horizontally and induction vertically. Professor Schwartz's curves have the ordinary relation inverted, and I think this has led to an obscurity in the wording on pages 704 and 706. The inclination of the curve spoken of is to the vertical and not to the horizontal axis. I think an analogous series of hysteresis loops can also be obtained with iron, when magnetised with a pulsating unidirectional current. After the first application of current the iron loses most of its magnetism on the cessation of the current, but apparently its recovery from the process of magnetisation is less complete as the cycles proceed. I do not know whether the geometrical progression followed in the case of hysteresis loops in the paper would apply in that case also. It would be interesting to consider whether there is any intimate relation between the behaviour of the materials in the two cases. Apart from the interest of the paper itself, I think it is suggestive of many exceedingly interesting directions in which further investigations might be made. If the mechanical property could be taken as a sort of standard indication of the physical nature of the rubber, it would be of great value from the mechanical test alone to find the relation between this mechanical standard and the various other properties of the rubber, such as its insulation, dielectric strength, and what ought to be closely analogous to it, the dielectric hysteresis constant when rubber is used in an alternating-current cable. I should imagine that there must be an intimate connection between the power absorbed in the electric stresses and the hysteresis losses when subjected to an intermittent mechanical stress. The durability Professor Schwartz states to be dependent upon the same properties as the mechanical hysteresis, and I think that further light on that point would be valuable.

Mr. Barnes. Mr. A. S. L. BARNES: I should like to ask Professor Schwartz if his tests on the rubber are intended to deal with the properties of the rubber from the point of view of durability, or of the dielectric strength, or both. I should imagine that the tests, being mechanical, would have reference to the former rather than to the latter.

Mr. Atchison. Mr. C. C. ATCHISON: I am sure that a machine or instrument which will enable us to get hold of and understand the properties of rubbers with which we have to deal in wiring and cable work will be of material use. I remember a few years ago Mr. Beaver said the best method of obtaining good cable suitable for its purpose was to deal with a good firm. Mr. Brooking, from a seller's point of view, says that so long as

a salesman can take something with him which will allow him to test other people's rubber and place them at a disadvantage, whether it be by smartness in the thumb movement or otherwise, he will be successful. As a buyer one is not quite satisfied, and wants something which will check the maker and seller. I notice the word "hysteresis" has been used. I do not know whether "hysteresis" is a technical word in connection with rubber, or whether Professor Schwartz has taken the name used for a similar magnetic effect in iron and used the name for something which he has produced himself. Mr. Atchison.

Mr. S. J. WATSON: In regard to the tests which Professor Schwartz has carried out, I assume that all the strips tested were cut off a length of finished cable, and consequently consist not only of vulcanised rubber, but also of a layer of pure rubber. The tests will be of value if all the test-pieces are exactly the same thickness of pure and of vulcanised rubber, but I understand that the thickness of one or the other is likely to vary slightly, although both together may give the same measurement. I should therefore like to ask the author whether the thickness of the pure and of the vulcanised rubber is the same in all cases when samples by different makers were compared with one another. I have always thought it unfortunate that vulcanised rubber cable will not give good results when laid under ground. It is exceedingly light and flexible to handle, and is easily manipulated in connection with street work, but the experiences which many of us have had in the past entirely put it out of court at the present time. In connection with the remarks of a previous speaker, I would also express a hope that at some future time Professor Schwartz will carry his experiments farther and give us the results of the ageing of rubber. Most of the tests have been made on rubber practically new from the manufacturer, but there is no doubt that deteriorating effects take place for a term not only of weeks, but of months and years. It would take a long time to carry out such tests, but I think the information obtainable would be of very considerable interest. Underground cables are subject to considerable variation in temperature due to both internal and external causes, and also to changes in the humidity of the atmosphere; both these undoubtedly affect the life of the rubber. In regard to the transmission of heat through rubber, the table which Professor Schwartz gives is of value, and, although the maximum does not occur until after some ten minutes, it is of interest to notice that 94 per cent. occurs in one minute. I had been hoping that some of our friends, the cable makers, would have given us a little information in regard to loading matter and substitutes, which seem to consist principally of zinc oxide, oil substitutes, and French chalk. I have heard that the vulcanised rubber of the cheap-grade cables imported into this country becomes very similar in appearance to putty after a short exposure, that is to say, it resolves itself into its original elements—boiled oil and whitening—or, in other words, oil substitutes and French chalk. The degree of vulcanisation is of the greatest importance, but I should imagine that it is not possible to say that a certain temperature and Mr. Watson.

Mr. Watson.

length of time for the process will be correct for all types of cable. It must vary with the percentage of Para rubber used and also with the kind of substitute employed in the mixing. By means of the interesting and ingenious machine designed by the author it is possible to test strips of vulcanised rubber and to ascertain approximately the percentage of high-grade rubber used in its manufacture, but I am not at all sure that this test will enable us to judge the value for electrical purposes of any particular sample. A given mixture may contain 60 or 70 per cent. of Para and test out well on the machine, but, owing to some defect in manufacture or to the type or character of the remaining 40 or 30 per cent. of substitute or loading, it might be quite unsuitable for cable insulation or for use in exposed positions.

Dr. Schidrowitz.

Dr. P. SCHIDROWITZ (*communicated*): Although the paper deals substantially only with the testing of coverings for electrical cables, there is much in the paper that should be of great use to those who work on other varieties of rubber. I see no reason why the principles underlying much of the work done by Professor Schwartz should not be applied to general work, nor why the direct method of obtaining hysteresis curves should not be adapted to any of the better types of testing machines. With regard to the nature of test-pieces and grips, I think that Professor Schwartz appears substantially to agree with the views expressed by myself and others, namely, that for exhaustive tests the ring method is the only practicable one. I quite agree that in the case of cable covers it can only be used for large sizes, failing the preparation of a special test-piece. I think, however, that if manufacturers and consumers seriously desired to deal with this matter there would be no great difficulty in doing so. It is easy to prepare a test-piece which is, during vulcanisation, of the same thickness as the bulk of the goods. If the goods are very thick a test-piece can be prepared in the shape of a disc, which may subsequently be cut in a cutting lathe to sections of the desired thickness for testing. The only rational alternative to the ring method is that suggested by Professor Schwartz, which he admits implies the restriction of the test within limits which are very appreciably removed from the maximum load. The result of this, particularly in the case of high class goods, is that the most characteristic features of the curve are not reached. At extensions of 300 per cent., stage 3, as will be seen on reference to the curves of Professor Schwartz and others, has scarcely commenced in the case of high-class soft rubbers. I am not sure that I agree with Professor Schwartz when he says that successive cycles, when they become constant, are characteristic of the material concerned. This can only be so within very narrow limits, particularly if the extension is far removed from being exhaustive. It will be understood that I am speaking of rubber goods generally, and not only of cable coverings. Concerning the latter, I think that Professor Schwartz has made out a very good case in regard to the lines suggested by him, but even here I think that the limits of the hysteresis curves which he proposes are perhaps unduly lenient towards the

inferior grades. I agree with him that tests under constant extension are very valuable, at any rate when applied to homogeneous material, and as regards any general schedule of contract testing I should like to see a test of this sort included. In the same way I think that valuable as are the hysteresis curves and the results which may be obtained from them, the curve which is obtained by taking the rubber right up to the break is highly characteristic, and should not be excluded. Professor Schwartz's work has confirmed my opinion that a bald figure for "permanent" or "sub-permanent" set is in itself of very little value. It seems to me, however, that the value of the work done divided by the sub-permanent set under standard conditions might be of utility. There can be no doubt that before satisfactory standard physical methods of testing rubber are introduced a great deal more work will be necessary, but in regard to cable coverings it seems to me that the suggestions made by Professor Schwartz (page 734), if not exhaustive, are both reasonable and practicable. I am inclined to think that it would be a mistake to try to impose on the manufacturer any further restrictions regarding his materials or processes. The consumer should deal with the article as such, and if it does its work in a satisfactory manner it should be a matter of indifference to him how it is made. Specifications enjoining the use or non-use of certain materials or of certain vulcanisation temperatures, etc., are likely to be very objectionable to the manufacturer without yielding any corresponding benefit to the consumer. So much depends in manufacture on details of the methods employed that it is next to impossible for any one not intimately connected with the rubber industry to formulate restrictions regarding materials and processes. Taking, for instance, Table V., dealing with the use of substitutes, it is fairly plain from the low breaking strains of all the samples, including that of number 1379, which contains 60 per cent. of rubber, that all the rubbers of this series are very poor specimens. Thus an article containing 60 per cent. of rubber, provided the rubber is of any ordinary good quality, can, if vulcanised under the most suitable conditions, be made to show a breaking strain of from 1,000 to 1,500 grammes. It is apparent, therefore, that using exactly the same materials and the same quantities of materials, two different manufacturers may produce two very different articles. There can be no doubt that satisfactory chemical and physical tests for the finished article would be of the greatest benefit to manufacturers and consumers alike, but it is only by intimate and cordial co-operation of the various sections of manufacturers and consumers and of those who have made this subject a special study that a practical working system can be evolved. Dr. Schidrowitz.

Mr. C. BEADLE (*communicated*): Professor Schwartz is correct, I think, in his assumption that the volume of the sample remains constant throughout the test. On this point we have made a number of determinations by the ring method on the machine we have devised. The tests were mostly done on hard-cure Para and plantation rubbers vulcanised with 6 per cent. of sulphur under varying conditions of Mr. Beadle.

Mr. Beadle. cure. The specific gravity of the rings was determined immediately before and after the test had been applied, and no change of volume could be noticed. The same appears to be the case in some mixtures containing mineral matter, although this point has not been so carefully investigated. I am inclined to think that where differences of volume take place, either during the extension or compression, that it is in cases of porosity, and that the air spaces only undergo change of volume. At any rate, no difference of volume has been noted within the limits of sub-permanent set on mineral-free specimens.

I agree with Professor Schwartz that the ring-shaped piece gives the best results in the determination of the breaking load. We have found a greater degree of accuracy in the small rings employed on our machine than is recorded by the Schopper machine. I went to Berlin some months ago, with the object of ascertaining what was being done in regard to the testing of rubber in the Government testing laboratories at Groszlichterfelde. By the courtesy of Professor Martens I was shown the apparatus which they employ for the purposes of tensile strength and elongation. They use the Schopper machine, which, as the result of Professor Memmler's researches, has been modified to suit their requirements. The machine as constructed, however, is only able to test rubbers which show an elongation up to about ten times the original length. This arrangement would not do for a large range of mixtures. The Schopper machine will therefore have to be lengthened, or a smaller ring substituted, if the machine is to be used for different classes of products. I prefer the small ring, such as we employ, because rubber goods of moderate dimensions can be cut into strips in any plane, either transversely or longitudinally, and so tested. It is possible by such means to show the differences of physical properties in different planes in solid articles of moderate dimensions. It would be interesting to know what the nature of the hysteresis loops would be if strips are cut across the sheet stripped from cable covering. The ring method (which, I think, might with advantage be applied to the author's hysteresis machine) nullifies the difference in the pieces cut in the same plane, but at different angles. In fact, it should give an average result of all directions in the one plane, which, I presume, is what is needed, and not the physical qualities of a strip in one direction only. The difficulty to which Professor Schwartz refers of ensuring a uniform degree of vulcanisation makes it impossible, in my opinion, to draw any definite conclusions from tests made on samples of different percentages of rubber, unless, perhaps, the whole history of the manufacture of the sample is known. The reason is, that there are so many factors, of which the percentage of rubber is only one, which determine the physical qualities of the finished product. The importance of uniformity of temperature (and possibly humidity), cannot be too strongly emphasised; this certainly applies to the determination of such things as the sub-permanent set, which forms a necessary part of the hysteresis loop. This can be better realised when it is remembered that if a stretched vulcanised thread is frozen for a sufficient

length of time, after the tension is removed no contraction takes place (*i.e.*, sub-permanent set = 0). If, now, the thread be placed on the hand, the warmth of the hand will cause the thread to contract. Also, when a number of strips are tested for sub-permanent set by stretching to four times their original length for 24 hours, and releasing, at the moment of release, and for the first few seconds, there is a visible shrinkage. We take our measurements after the first 30 seconds, and then after 6 hours, but if the pieces are handled or breathed upon, they are seen to move, showing how extremely susceptible the pieces are to atmospheric influences. The figure for sub-permanent set varies therefore in a large measure according to atmospheric conditions. Presumably Professor Schwartz's sub-permanent set, as shown by his hysteresis loops, will represent the percentage extension immediately after release, and I can confirm what he says in regard to the difficulty of measuring this in some mixtures immediately after release, as the strips continue visibly to contract. In comparing mixtures containing different percentages of Para it should be borne in mind that the differences in the curves shown may be as much the result of differences in the vulcanisation as in the percentages of rubber. It could not be argued, therefore, that a certain loop would hold good for a certain mixture, but if from a certain definite manufacture different kinds of loops were produced, it would appear that something in the manipulation had varied, and therefore the machine should be of great utility in the hands of the manufacturer as well as to the engineer. I should like to see the results as obtained by the author in connection with the influence of cross-sectional area on test-pieces, confirming Stévart's law, repeated on strips cut transversely and longitudinally from solid rubber goods in the way that we have done in the testing of solid tyres. Referring to Table II., it is perhaps difficult to arrive at the "normal vulcanisation," which would vary somewhat with the ideas of the manufacturer. I hardly think it justifiable to describe "decrease in tension" as "deterioration." The decrease in tension with constant extension is a measure of the want of rigidity of the rubber, *i.e.*, the extent to which it flows under extension. This is a quality which may be just the reverse of deterioration in the ordinary sense of the word (*i.e.*, "perishing" qualities). Those mixtures which show the "decrease in tension" most are the least likely to perish, such as in the under-vulcanised samples. Having regard to this fact, the remarks made on "deterioration" are open to misinterpretation. Considerable rigidity under tension might be rather a disadvantage than not, and the quality of decrease in tension with constant expansion, *i.e.*, ability to flow, would be useful to a covering which is forced into another position by bending, and able automatically to relieve the tension. Then, again, when comparing vulcanisation, the amount of vulcanisation as determined by time is not the same as the "coefficient of vulcanisation" as determined by chemical analysis. The latter is measured by the amount of sulphur entering into combination with the rubber, and when compared with the physical qualities of a rubber of definite Mr. Beadle.

Mr. Beadle. composition should yield valuable results. Further, it must not be lost sight of that the vulcanisation varies in kind as well as degree, all of which considerations affect the physical qualities of the final product. Referring to Tables IV. and V., a further set of physical tests was done on these samples, to show the effect of "substitute." It will be noticed that the elongation of rupture is very nearly 1,000 per cent. on original length for each of the mixtures down to about 20 per cent. of substitute, but when these samples were kept another thirty-eight days and tested, that containing no substitute showed an improvement in stretch, whereas the others all showed a loss in strength increasing with the amount of substitute added. The gain in stretch at break with no substitute was 78 per cent.; with 10 per. cent. of substitute the loss was 22 per cent.; with 20, 135 per cent.; with 30, 137 per cent. Often when a sample on keeping shows loss in stretch at break, accompanied by an increase in strength at break, it is a proof of incipient deterioration, which later on results in loss of strength and perishing. The strength per unit of stretch we find to be a useful figure. No doubt all these factors would find expression in some way or other in the hysteresis loops produced by Professor Schwartz's machine.

Looking at "substitute" from a chemical point of view, I have shown in a recent paper* that when analyses are made of mixtures of known composition, the amount of rubber found by analysis (particularly in mixtures containing considerable percentages of mineral matter) is much less than the actual amount of rubber used in the mixture, and the figure which would be reckoned as substitute may be as much as 20 to 40 per cent. on the weight of the added rubber, or 10 per cent. on the sample. The rubber is more or less changed, in the course of vulcanisation in such mixtures, into something which is certainly of no more value to the physical qualities of the product than "substitute" is; consequently, when substitute is added in small quantities, the change in the physical qualities is not marked, and it is conceivable that the presence of a small amount of substitute may in itself have the effect of retarding any injurious effects that the sulphur may have upon the rubber, and by so doing result in producing a mixing which contains as much actual undecomposed rubber as when no substitute is added. This is quite conceivable, and, if true, is in the defence of the use of small quantities of substitute.

The employment of hysteresis loops should prove of great value in recording the physical qualities of rubber. In order, however, that we may know what interpretation to put upon these curves, it will be necessary to conduct a very large number of tests upon specimens of known history and origin. The first and easiest employment of this machine would appear to be by the manufacturers themselves, who obviously have at their disposal the means of testing its value.

Professor Schwartz. Professor SCHWARTZ (*in reply*): With regard to Mr. Whalley's contention that test-pieces cut from a given cable covering may vary in thickness, I would point out that the minimum thickness of insulation

* *The Analyst*, January 10, 1910, "The Analysis of Rubber Goods."

Professor Schwartz.

for C.M.A. cables is already standardised, and I do not think that there would be any difficulty in specifying a "tolerance" in the curve obtained which should allow for a reasonable variation from the standard thickness. In any case the results from three test-pieces, as suggested in the paper, may be relied upon as giving an average value. Further, the results obtained from one test-piece may be directly compared with those obtained from another of different cross-sectional area, by means of their equivalent triangles corrected for the difference of section. Mr. Whalley's interpretation of the differences between Figs. 13 and 16 is correct; with regard to Fig. 14, the initial tension was measured in grammes, and the decrease in tension after the lapse of a given number of hours was plotted as a percentage of this initial value. In Fig. 15 the decrease in tension in grammes per hour is plotted as a percentage of the inital tension. I am of opinion that the constant load tests do not give such consistent results as the successive cycle tests. With regard to the area of the hysteresis loop decreasing as the percentage of rubber in the mixing is increased, I recognise that the area of the loop is affected not only by the amount of rubber or other elastic material present, but on the character of this material and its degree of vulcanisation. All these three factors are apparently closely concerned with the electrical properties of the cable covering and with its durability, and I think that a careful correlation of the results obtained from the hysteresis, electrical, and durability tests will enable this connection to be established. Mr. Whalley sets out at length a list of variables which affect the area of the hysteresis loop. Most of these, however, such as dimensions of test-pieces, speed of working, and temperature of test, are readily standardised, leaving only the three factors referred to above as requiring further consideration, in order completely to interpret the hysteresis loop. The distinctions referred to by Mr. Beaver between high- and low-grade rubbers were made with reference to the relative ease with which compounds containing various percentages of rubber may be cut, and in this respect there is a very great difference between the behaviour of a compound containing 88 per cent. rubber and one containing only 33 per cent. No disparagement was intended of the 600-megohm grade cable, which in the C.M.A. grades I recognise as being excellent material for the purposes required.

In reply to Mr. Cramp, the hysteresis loops are plotted with the load as ordinates and the extensions as abscissæ, in accordance with the usual convention followed in load-extension diagrams. Test-pieces of various lengths but of the same cross-sectional area extend under a given load in proportion to their lengths for specimens of 3 in. length and upwards; for shorter test-pieces the grips seem to exert a disturbing influence. The hysteresis machine may be made up by any one who so desires without any restriction on my part.

Mr. Cormack's suggestions as to the form of test-piece are interesting, and should most certainly be tried. The difficulty of testing complete tubes of insulation from large-size cables with the hyste-

Professor Schwartz.

resis machine, as at present designed, is that large stretching forces would be required, and the machine would have to be considerably strengthened; but I do not anticipate that there would be any difficulty in doing this.

In reply to Professor Marchant, a very complete examination of the electrical properties of rubber insulation has been made by H. W. Fisher, and his results are given in a paper read before the American Institution of Electrical Engineers on June 25, 1907. With regard to the Ceylon rubber referred to as giving good results when tested mechanically but bad results when incorporated in a cable, this is due to the fact that, when first introduced into this country, the cultivated Ceylon rubber was treated by the cable makers by the same methods as they had been accustomed to apply to wild Para rubber. Bad results followed this procedure, but now that they have modified their methods of treatment the Ceylon rubber is yielding very good results, and is being extensively employed in high-class work.

Mr. C. F. Smith has raised a very interesting point as to the hardening of rubber when at rest. There is no doubt that a very considerable molecular change takes place, which I am hoping to investigate; I can only say at present that the hysteresis loop obtained from specimens which have become hard from resting is quite abnormal in shape, the sudden change in the molecular structure of the material being clearly shown on the diagram.

In reply to Mr. Barnes, I may say that the hysteresis tests are intended as an indication of the initial quality of the compound, and it is suggested that loops obtained after heating or other deterioration tests will give a clue as to the probable durability of the compound. The term "hysteresis" is applied because the release curve in the diagram "lags" behind the extension curve.

Dr. Schidrowitz, in his interesting communication, has made a number of valuable suggestions, which I hope may be fruitful in results. I agree with him that it is a mistake to try and impose upon the manufacturer restrictions regarding his materials and processes, and that it is better to specify tests applicable to the finished article.

I cannot agree with Mr. Clayton Beadle that the ring-shaped test-piece will give an average value for the extensibility of the material both with, and across, the grain, as it seems to me that the dominant factor in the result obtained will be due to that portion of the ring in which the material is weakest. I am, however, in agreement with his suggestion that the ring-shaped test-piece may be applied to the hysteresis machine with advantage in the case of many articles other than cable coverings. I further agree that the accurate determination of the sub-permanent set is a matter of considerable difficulty, as the material on release is in a very sensitive condition, and the successive cycle test, where the successive increments of extension are obtained under very definite conditions, is much to be preferred.

THE INFLUENCE OF VARIOUS COOLING MEDIA UPON THE RISE IN TEMPERATURE OF SOFT IRON STAMPINGS.

By R. D. GIFFORD, M.Sc., Student.

(*Paper received from the* BIRMINGHAM LOCAL SECTION, *October* 7, 1909, *and read at Birmingham on February* 16, 1910.)

The temperature rise of electrical machinery is one of the most important of the many considerations to which the designer has to pay attention, since the resistance of the copper conductors increases as their temperature rises, thereby affecting the regulation of the machine, and also because of the danger of damaging the insulation if the temperature rises above certain limits.

The heating of the iron stampings of transformers subjected to an alternating flux, is due to the hysteresis and eddy-current losses. The latter may be greatly diminished by various methods.

As this loss is proportional to the square of the frequency, induction, and thickness of the iron plates, a reduction of any or all of these reduces the eddy-current loss very considerably.

It may also be reduced by insulating the stampings by inserting sheets of thin paper between each, or by other non-conducting coatings on their surfaces.

The hysteresis loss is dependent upon the frequency, induction, and magnetic properties of the iron. This source of heating may be reduced by a suitable choice of the first two, or by using iron of high permeability, such as "Stalloy" iron, in which the carbon is to a great extent replaced by silicon.

But apart from the choice of iron used, thickness of plates, induction, etc., the temperature rise is obviously greatly affected by the external conditions, such as the amount of exposed surface of iron and the medium in contact with the surface.

The heat must escape from the iron by radiation, conduction, and convection. This implies a flow of heat from the iron surface into the surrounding medium, and the fact that a hot body takes a certain time to cool down further implies that there must be a resistance to the flow of heat, otherwise the heat would escape and the body would instantly assume the temperature of its surroundings.

The flow of heat will therefore depend upon the resistance offered to it, and also upon the temperature difference existing between the iron and the substance in contact with it. In fact, we may treat the flow of heat from a body in the same way as an electric current, heat flow per sq. cm. of surface in thermal units taking the place of current and temperature difference that of potential difference. We have, therefore—

$$\text{Heat flow per sq. cm.} = \frac{\text{temperature difference}}{\text{resistance}}.$$

In the case of heat, however, the resistance or its reciprocal, the conductivity, is made up of three distinct factors—viz., conduction, convection, and radiation—and the last two are not constant quantities which depend upon the nature of the substance, as in the case of electrical resistances. The radiation depends upon the temperature difference, the nature of the surface, whether smooth or rough, dark or bright in colour.

The convection will depend upon the temperature rise of the medium, its coefficient of expansion, its viscosity, the roughness of the surface, and the path of the convection currents. Therefore the law relating to the flow of heat, although it can be put in the form of Ohm's law, is in reality much more complicated than this, but if the law governing the variation of resistance under various practical conditions can be determined, then the temperature rise of the apparatus is found if we also know the heat flow—that is, the energy dissipated as heat.

The object of the research, then, was to determine the conductivity to heat flow existing between the surface of a cylinder made up of soft iron stampings and such cooling media as air and oil under the following conditions :—

1. Air, when the iron was (*a*) free in air, (*b*) enclosed in an iron case.
2. In a case, with draught of air flowing over the surface of the iron.
3. With iron surrounded by oil.
4. Iron in oil, and with cold water circulating through a cooling worm immersed in the oil.

Description of Apparatus (see Figs. 1 and 2).—The apparatus consisted of about 300 soft iron discs, each 0·51 mm. thick, 16·8 cms. in diameter, and having 32 holes, each 0·5 cm. diameter, punched near the circumference, and a central hole 4·4 cms. diameter. These discs were clamped tightly together by means of four temporary bolts passing through the small holes, so forming a cylinder 16 cms. in height. The whole was then wound in gramme-ring fashion—that is to say, up an outer hole and down the centre, the bolts being removed as occasion demanded until all the holes were wound, double cotton-covered copper wire, 1·41 mm. diameter, being used. At the top and bottom of the

cylinder, on the circumference, fibre washers were placed, to insulate as far as possible the flow of heat longitudinally, and also to protect the winding from damage by the wooden end discs. The two free ends of

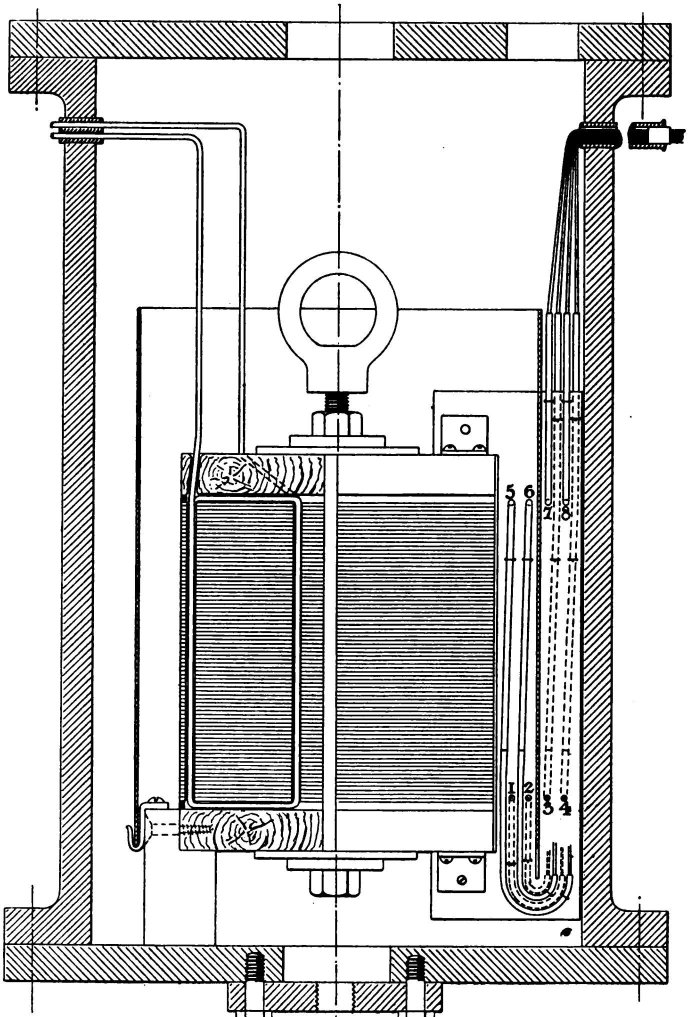


FIG. I.

the winding were brought out at the top through the disc, and the whole bolted firmly together by means of a ½-in. bolt. The case, in which the tests with air blast and oil cooling were conducted, was made

of cast iron of circular section, having top and bottom plates bolted to the flanges.

Measurement of the Energy absorbed in Hysteresis and Eddy Currents.—The energy absorbed by hysteresis and eddy-current losses in the iron was measured by the three-voltmeter method. Only one instrument was used for measuring the three voltages and the current. This was a Duddell thermo-ammeter supplied by the Cambridge Scientific Instrument Company, and consists essentially of a small heater in the form of a lamina of platinum deposited upon a sheet of mica 0·75 cm. long and 0·5 cm. in width. The platinum is scraped away in places so as to form a grid. Suspended over this heater, and in close proximity

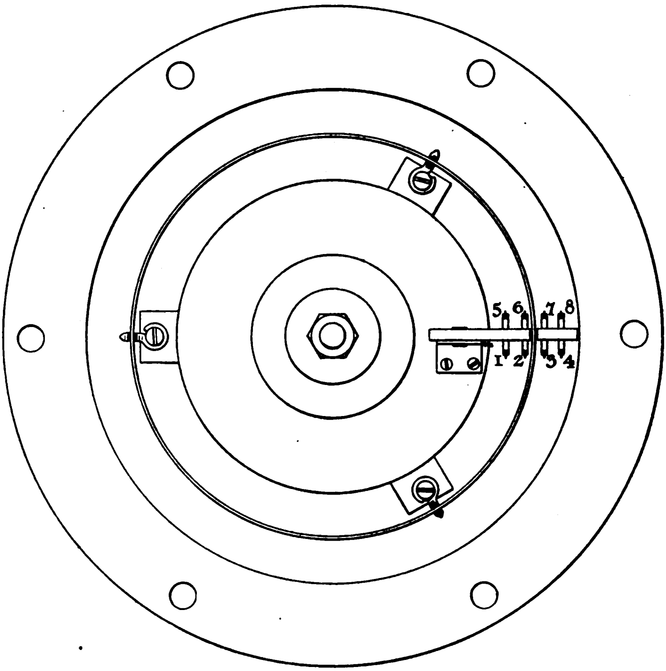


FIG. 2.

to it, is one end of a thermo-junction, whose wires are connected to a copper coil suspended in a strong magnetic field.

On the passage of a current through the heater, whose resistance was 160 ohms, the thermo-junction becomes heated, thereby developing a current in the coil and producing a deflection of the pointer. The maximum scale reading of the instrument was 10 milliamperes.

Fig. 3 shows a diagram of the connections of the instrument and of the supply circuit. The power was obtained from a 6-k.w. Westinghouse rotary converter, having six slip-rings connected to tapping-

points on the armature, so that various voltages could be obtained at 50 frequency.

From the converter, leads were taken to a Burnand transformer T, having a split secondary winding, giving a step-up transformation of two or four times the primary voltage.

In series with the secondary winding were placed a main current regulator R_1, a non-inductive resistance R_2, which consisted of fifteen 110-volt lamps in parallel, a manganin resistance R_3, shunted by the thermo-ammeter for the purpose of obtaining the current in the circuit, and the apparatus.

The resistance R_3, of which two were made, giving maximum scale deflections on thermo-ammeter with 3·5 and 1·75 amperes respectively, consisted of strip manganin mounted between terminals on a hard

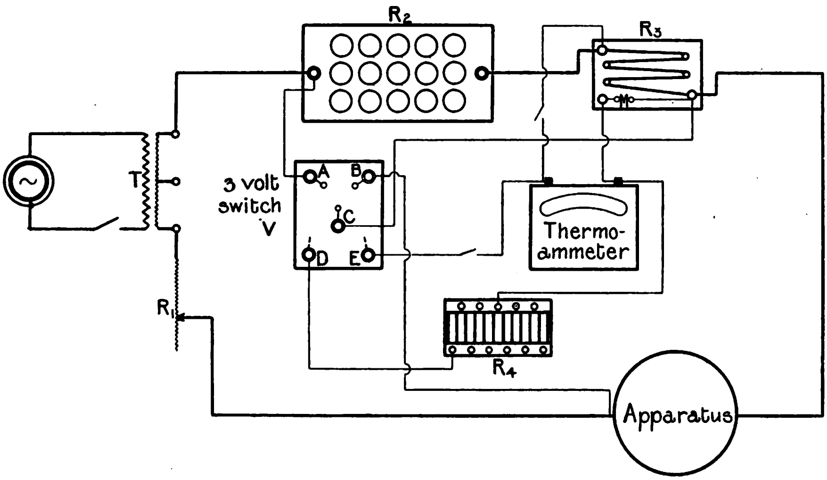


FIG. 3.

wooden base. These terminals were connected to the thermo-ammeter through a tapping key and mercury cups M, a small copper fork being used to connect the cups.

To read the voltages, the volt switch V was used. This consisted of three terminals, A, B, C, which were connected to mercury cups at the apices of an equilateral triangle, and mounted on a paraffin wax block. The terminals A B were connected across the supply, B C across the apparatus, and A C across the non-inductive resistance.

The voltage across any two terminals could be taken to the terminals D E, and so to the thermo-ammeter, through the series resistance R_4, by means of two copper legs insulated from each other by being mounted on ebonite, and so spaced that they dipped into the mercury cups. The series resistance R_4 consisted of 10 coils of No. 40 double silk-covered resistance wire, non-inductively wound on rectangular

sheets of micanite. Each resistance was approximately 1,000 ohms. These were all connected in series and mounted in an ebonite framework, a terminal being placed at each junction, so that any resistance from 1,000 to 10,000 ohms could be used.

The advantages of the thermo-ammeter are:—

1. The heater has practically no self-induction or capacity, so that the instrument can be calibrated by direct-current instruments, and used on alternating-current circuits.
2. Practically no power is taken by the instrument, the maximum scale deflection being produced with a consumption of only 0·015 watt.
3. As the power it would be necessary to supply to the apparatus to produce a satisfactory rise in temperature under the different conditions of cooling was unknown, such an instrument was very valuable, as additional shunt and series resistances could be made if necessary.

Its disadvantages, so far as its present purpose is concerned, are that—

1. As in all hot-wire instruments, its action is sluggish, so that when four readings are to be taken to obtain the power supplied to the apparatus a liability to error occurs, due to slight changes in the supply volts during the interval occupied in taking the readings.
2. The deflection is approximately proportional to the square of the current, and therefore gives a very close scale at the zero end, necessitating a certain amount of manipulation of the series resistances to give a deflection well towards the open end of scale with each of the three voltages to be measured.

The instrument with its shunt and series resistances was carefully calibrated by standard direct-current instruments.

To obtain the watts supplied to the apparatus we have—

$$W = \frac{(E^2 - E_R^2 - E_L^2)\,I}{2\,E_R},$$

where—

I = current in amperes.
E = total volts across apparatus and lamps.
E_R = volts across lamps.
E_L = volts across apparatus.

The Measurement of the Temperature Rise of the Iron and Cooling Medium.—This was effected by means of thermo-couples. As the drop in temperature, down the air or oil separating the iron of the apparatus from the outside case, was not expected to be very considerable, it was

necessary to use a combination of metals giving a sensitive thermo-couple.

With the object of finding such a couple experiments were made with combinations of well-known alloys and copper in the form of double silk-covered wires. The thermo-couples to be tested were placed in glass tubes with the junctions projecting beyond the end of the tubes, which were immersed in oil contained in a copper vessel. A delicate thermometer reading to 0·1° C. was also placed in the oil close to the junctions. The oil tank was wound on the outside with resistance wire and heated by the passage of a current.

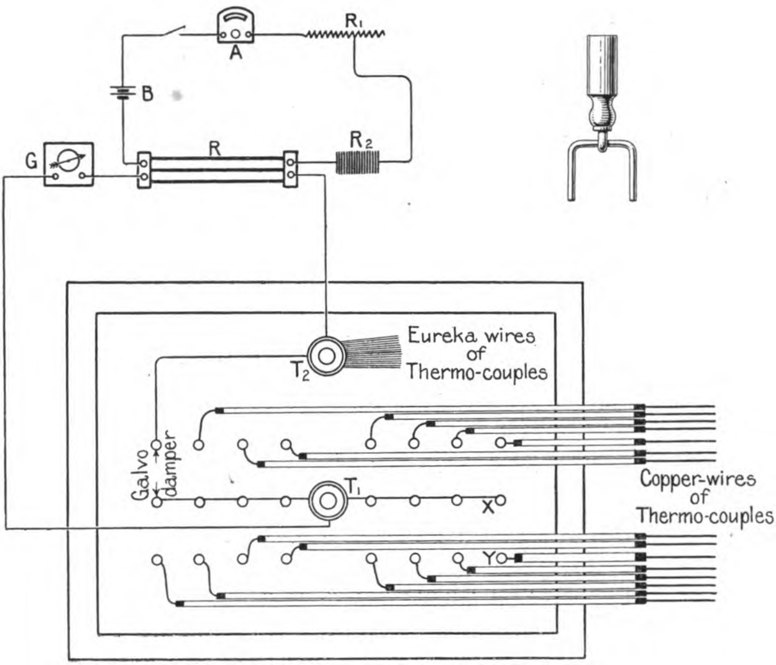


FIG. 4.

Fig. 4 shows the apparatus used for determining the electromotive force generated by any particular couple. It consists of a paraffin wax block arranged to accommodate fifteen thermo-couples and a galvanometer damper. The eight mercury cups in the central row are connected to the terminal T_1, and thence to the reflecting galvanometer G, the low resistance R, and to terminal T_2. All the alloy wires of the thermo-couples were connected to T_2, and the copper wires to the other mercury cups in the block, being kept in position by passing through narrow glass tubes embedded in the wax. A copper fork mounted in an ebonite handle, as shown in Fig. 4, connected any

couple to the galvanometer circuit by placing it in the mercury cups such as xy.

The deflection of the spot of light on the scale was brought back to zero by sending a current from the 4-volt accumulator B through the known resistance R. The current was read by a Siemens and Halske standard ammeter A, and adjusted to the necessary strength by the rheostats R_1 and R_2.

This "null" method of determining the electromotive force of a couple is extremely convenient and accurate, as only a short scale is required, and it eliminates the results of the "Peltier effect" and the "drop" in the thermo-couple wires and galvanometer. That these effects were very appreciable in the case of a copper-eureka couple used in the subsequent tests was shown by finding the separate deflections of the spot of light, due to the couple alone, and the E.M.F. down R alone, after bringing the spot of light to zero. Several such readings were taken, the following being an example :—

> Deflection due to current in R alone = 238 divisions to the right.
> Deflection due to thermo-couple alone = 195 divisions to left.
> Deflection due to both together = zero.

Hence the combined "Peltier" and "drop" effects are very considerable, and are eliminated by the zero method.

The temperature of the oil at the junctions and of the air at the paraffin wax block switch being known, and the E.M.F. of the couple for these temperatures determined, we find the micro-volts per degree difference between the hot and cold junctions.

The alloys used were manganin, german silver, constantan, platinoid, and eureka with copper. All the alloys were electro-negative with respect to copper, and gave practically constant values of micro-volts per degree within the limits of the temperatures used—viz., 15° C. to 80° C.

The values found for the different couples were :—

Copper-Manganin ...	...	1·810	micro-volts	per 1° C.
„ German silver	...	13·160	„	„
„ Constantan...	...	17·700	„	„
„ Platinoid ...	...	24·000	„	„
„ Eureka ...	...	44·415	„	„

The copper-eureka couple was therefore chosen for use in measuring the various temperatures required. The value of the manganin resistance R (Fig. 4) was 444·7 microhms, hence the current I required to bring the spot of light to zero for a temperature difference t° C. is—

$$I = \frac{44{\cdot}415 \times t}{444{\cdot}7} = \frac{t}{10{\cdot}01},$$

or very approximately the temperature difference is given by multiplying the reading of the ammeter by 10.

Approximate Calculation of the Conductivity to Heat Flow from Iron to Air.*

Heat Carried Away by Conduction and Convection.—When a heated surface is exposed freely to air, the air in the immediate vicinity becomes heated, and therefore rises carrying away heat. It may be assumed that this action is confined to a comparatively thin layer of thickness δ cms. Let the surface be S sq. cms. at T° C. above air temperature. If C be the conduction coefficient of air, then the heat dissipated by conduction in the length δ is—

$$P_1 = C\frac{S}{\delta}T.$$

The value of C in C.G.S. units is 0·00005551 (Landholt-Börnstein, Physikalisch-Chemische Tabellen), or in electrical units is $2{\cdot}32 \times 10^{-4}$;

$$\therefore \quad P_1 = 2{\cdot}32 \times 10^{-4}\frac{S}{\delta}T \text{ watts.}$$

This loss per second by conduction alone in still air has been found to be $4{\cdot}65 \times 10^{-4}$ watts per sq. cm. of surface per 1° C. difference in temperature of surface and air (Hütte). Hence—

$$P_1 = 2{\cdot}32 \times 10^{-4}\frac{S}{\delta}T = 4{\cdot}65 \times 10^{-4}\,S\,T \text{ watts.}$$

$$\therefore \; \delta = 0{\cdot}5 \text{ cms.}$$

Convection.—Let v cms. sec. be the mean velocity of the air travelling up the surface of height h cms. The time taken to move up the surface $= \frac{h}{v}$ seconds. The volume of heated air is $S\delta$, and if we assume a uniform temperature gradient from the iron to the air the mean temperature of this volume is $\frac{T}{2}$ above the surrounding air. The specific heat of air is 0·238 cals. per 1 gramme per 1° C., and 1 cubic metre of air at 15° C. and 760 mm. weighs 1·188 kgs., hence approximately for heated air we may say 1 cubic metre weighs 1 kg., therefore the specific heat in electrical units per cub. cm. is 10^{-3} watt-secs. Therefore the rate of dissipation of heat by convection is—

$$P_2 = 10^{-3}\,S\,\delta\,\frac{T}{2}\,\frac{v}{h} \text{ watts.}$$

Radiation.—The law governing the radiation of heat is that of Stefan-Boltzmann:—

$$H = K\,S\,t\left\{\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_0}{100}\right)^4\right\}$$

* R. Goldschmidt, "Die Grundgesetze der Erwärmung elektrischer Maschinen," *Elektrotechnische Zeitschrift*, vol. 29, p. 886, 1908.

where—

H = large calories.
T_1 = absolute temperature of radiating body.
T_0 = absolute temperature surrounding medium.
S = radiating surface in square metres.
t = time in hours.
k = constant depending upon the nature of the surface.

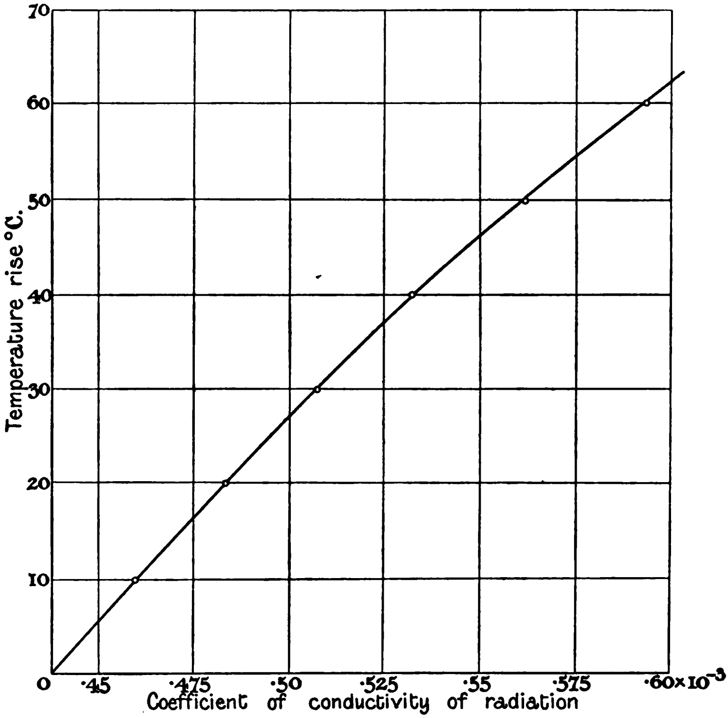


FIG. 5.

For ordinary dark metal surfaces $k = 4$ (Hütte). Reducing to electrical units and taking S in sq. cms. we have rate of dissipation of heat by radiation—

$$P_3 = 4{\cdot}6 \left\{ \left(\frac{T_1}{100}\right)^4 - \left(\frac{T_0}{100}\right)^4 \right\} 10^{-4}\ S \text{ watts.}$$

This formula may be simplified and put in the form $P_3 = C\,T\,S$, where T is the temperature difference, S the radiating surface in sq. cms, c the coefficient of conductivity of radiation.

The values of c are found from the Stefan law by assuming various values of T_1 and calculating P_3. The temperature of the air in the room

is assumed to be 14·5° C., this being the value in Test I., Table I. The value of c has been plotted against temperature rise in Fig. 5. If we allow a temperature rise of 50° C. the value of c is $5{\cdot}625 \times 10^{-4}$.

$$\therefore \quad P_3 = 5{\cdot}625 \times 10^{-4}\ \mathrm{S\,T}\ \text{watts}.$$

The total dissipation of heat by conduction, convection, and radiation is therefore—

$$P = P_1 + P_2 + P_3 = \frac{2{\cdot}32}{\delta} \times 10^{-4}\ \mathrm{S\,T} + 10^{-3}\ \mathrm{S}\,\delta\,\frac{\mathrm{T}}{2}\,\frac{v}{h} + 5{\cdot}625 \times 10^{-4}\ \mathrm{S\,T};$$

putting—

$$\delta = 0{\cdot}5$$

$$P = 10{\cdot}275 \times 10^{-4}\left(1 + \frac{0{\cdot}24\,v}{h}\right)\mathrm{S\,T},$$

or the total coefficient of conductivity is—

$$C = 10{\cdot}275 \times 10^{-4}\left(1 + \frac{0{\cdot}24\,v}{h}\right)$$

Test I.

The Temperature Rise of Iron Stampings Free in Air.—Three thermo-couples were placed in the iron between the stampings, and about ⅛ inch from the outside surface. The first was placed 2 cms. from the bottom, the second half-way up, and the third 2 cms. from the top of the stampings. The iron was heated up quickly by cutting out the main regulator, and when a suitable temperature was reached the watts were adjusted to about the right value to maintain this temperature, and then kept constant, readings being taken at intervals of half an hour until the temperature assumed a final value.

The results obtained are given in Table I.

Table I.

Iron Free in Air.

Room Temperature ° C.	Final Temperature Rise of Iron at—			Mean Temperature Rise. ° C.	Watts Dissipated.
	Top.	Middle.	Bottom. ° C.		
14·4	61·5	62·5	59·0	61·0	103·5
14·6	48·9	49·5	47·1	48·5	70·0
14·3	41·4	42·2	39·7	41·1	53·0
14·4	35·2	36·3	34·1	35·2	43·0
14·8	27·8	28·8	27·1	27·9	33·0
14·5	22·0	22·9	21·4	22·1	24·0

It will be seen that the middle of the iron always had a higher final temperature than the top or bottom, and that the temperature at the top is higher than at the bottom of the iron.

This is due to the fact that the energy lost in the upper half of the iron is equal to that in the lower half, but the temperature of the air surrounding the upper half is higher than that below, for the air rises in temperature as it travels up the hot surface. Consequently, if equal energy is dissipated the temperature at the top must exceed that at the bottom. This is much more evident in the case of oil cooling, as will be seen by reference to Test IV. A curve, Fig. 6, has been plotted of the average temperature rise of the iron and the total watts dissipated. The conductivity to heat flow at various temperatures can be obtained

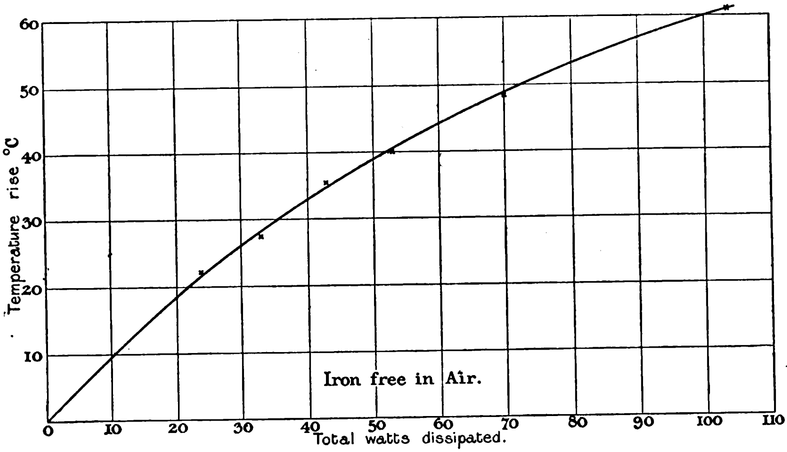
TABLE II.

Iron Free in Air.

Total Watts Dissipated.	Mean Temperature Rise of Iron. °C	Coefficient of Conductivity C.	Resistance to Heat Flow $R = \frac{1}{C}$
100	60·0	$1{\cdot}975 \times 10^{-3}$	506
90	56·6	$1{\cdot}882 \times 10^{-3}$	531
80	53·0	$1{\cdot}790 \times 10^{-3}$	559
70	48·7	$1{\cdot}703 \times 10^{-3}$	587
60	44·0	$1{\cdot}615 \times 10^{-3}$	620
50	39·0	$1{\cdot}520 \times 10^{-3}$	657
40	33·2	$1{\cdot}428 \times 10^{-3}$	700
30	26·0	$1{\cdot}367 \times 10^{-3}$	732
20	18·6	$1{\cdot}272 \times 10^{-3}$	785

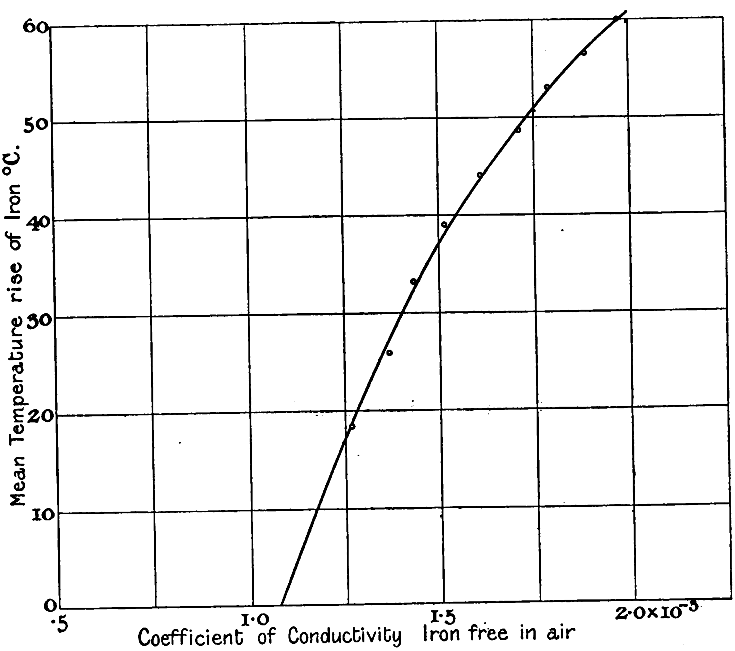
from this curve. Let W watts be the total energy dissipated as heat, T the rise in temperature of the iron over the surrounding air, and S the total exposed surface of the iron. Then the heat flow per sq. cm. is $\frac{W}{S}$, and as the heat flow per sq. cm. $= \frac{\text{temperature difference}}{\text{resistance}}$ $= \{\text{temperature difference} \times \text{conductivity C}\}$ we have $C = \frac{W}{ST}$.
The exposed surface of iron of the apparatus is 845 sq. cms. (diameter, 16·8 cms.; height, 16 cms.).

The values of the total conductivity as calculated from Fig. 6 are given in Table II. and plotted against temperature rise in Fig. 7.



60
50
40
30
20
10
Temperature rise °C
Iron free in Air.
0
10
20
30
40
50
60
70
80
90
100
110
Total watts dissipated.

FIG. 6.



60
50
40
30
20
10
0
Mean Temperature rise of Iron °C.
·5
1·0
1·5
2·0×10⁻³
Coefficient of Conductivity Iron free in air

FIG. 7.

From the calculated value of the conductivity—

$$C = 10{\cdot}275 \times \left(1 + \frac{0{\cdot}24\,v}{h}\right) 10^{-4}$$

it is evident that at temperature rise equal to zero, $v = 0$ and therefore $C = 10{\cdot}275 \times 10^{-4}$. Now, by producing the conductivity curve, Fig. 7, to cut the axis, the value of C at $T = 0$ is $10{\cdot}75 \times 10^{-4}$, which agrees almost identically with the calculated value.

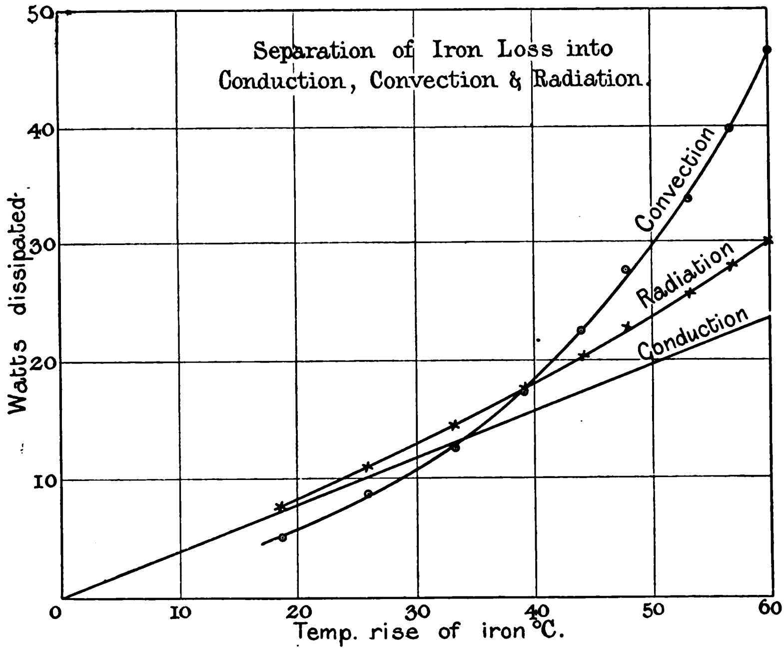


FIG. 7A.

The total iron losses in Table II. may be separated into the three components :—conduction, convection, and radiation.

The loss by conduction alone is found from—

$$P_1 = 4{\cdot}65\ S\ T \times 10^{-4} \text{ watts,}$$

and that of radiation from—

$$P_2 = C\ T\ S,$$

the values of C being taken from Fig. 5, and T from Table II.

The convection loss is found by difference. Fig. 7A shows the separate losses plotted against the temperature rise of the iron.

It is interesting to notice how quickly the quantity of heat carried

away by the convection currents rises in comparison with radiation or conduction.

The equation connecting the coefficient of conductivity and temperature rise in Fig. 7 is very nearly—

$$C = 10{\cdot}75 \times 10^{-4} + 0{\cdot}0725 \times 10^{-4}\, T^{1{\cdot}14}$$
$$= 10{\cdot}75 \times 10^{-4}\,(1 + 0{\cdot}00675\, T^{1{\cdot}14}).$$

Let σ be the watts dissipated per sq. cm. of iron surface. Then—

$$\sigma = 10{\cdot}75 \times 10^{-4}\,(T + 0{\cdot}00675\, T^{2{\cdot}14}),$$

from which—

$$T = 65\left\{\sqrt{1 + 25\,\sigma} - 1\right\} \text{nearly.}$$

This formula therefore gives approximately the temperature rise of iron stampings, exposed freely to air, in terms of the watts dissipated and the exposed surface. To test the formula the temperature rise has been calculated at various points and compared with the value obtained in the test.

Watts Dissipated.	Calculated Value of Mean Temperature Rise. ° C.	Experimental Value of Mean Temperature Rise. ° C.
20	17·0	18·6
30	24·4	26·0
40	31·2	33·2
50	37·4	39·0
60	43·4	44·0
70	48·8	48·7
80	54·3	53·0
90	59·5	56·6
100	64·8	60·0

Test II.

The Temperature Rise of Iron Stampings when Cooled by Air and Enclosed in an Iron Case.—The apparatus was now placed in the iron case as shown in Figs. 1 and 2. The holes in the top cover were closed. The temperature of the iron was measured by the same thermo-couples as in Test I. The temperature of the air at the top and bottom of the iron was measured by eight thermo-couples, four at

the top and four at the bottom. These were equally spaced between the iron and case, the distance between each being 1 cm. The couples were passed through glass tubes and supported in position by means of a brass plate screwed to the end discs of the apparatus. This plate was cut nearly to the bottom, midway between the apparatus and case, to allow of the insertion of a brass separating sheet surrounding the apparatus. All the couples between this sheet and the apparatus were taken to the bottom and brought up on the outside, thus avoiding the necessity of disconnecting any couple wires when placing the

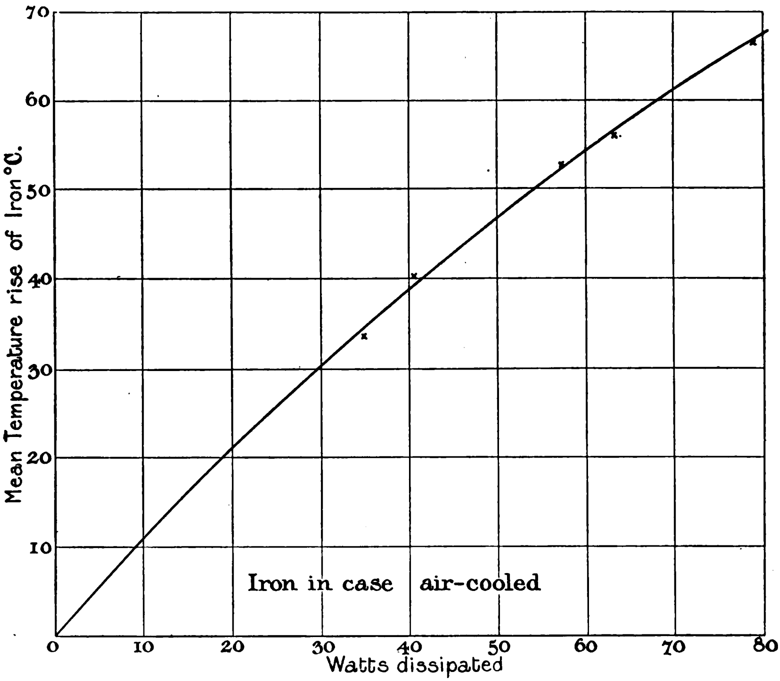


FIG. 8.

separating sheet in position or removing it. All the couple wires were taken through a large glass tube at the top of the case, and connected to the block switch as indicated in Fig. 4. The results obtained in this test are tabulated on page 769.

The temperature rise in this case shows a large increase over that for Test I. for the same watts dissipated, due, of course, to the fact that there is not a fresh supply of cold air constantly coming in contact with the iron. Also, the difference in temperature between the top and bottom of the iron is very much more marked than in Test I. as the hot air now collects in the upper part of the case.

TABLE III.

Iron enclosed in Case—Air Cooling.

Room Temperature. °C.	Final Temperature Rise of Iron.			Mean Temperature Rises. °C.	Watts Dissipated.
	Top.	Middle.	Bottom.		
14·3	69·00	70·5	59·85	66·45	79·0
15·2	58·00	59·0	51·00	56·00	63·5
14·8	55·00	56·0	47·50	52·80	57·5
14·9	42·25	43·0	35·50	40·25	40·7
15·1	36·00	35·5	30·00	33·80	35·0

From the above values, the curve of watts against mean temperature rise is obtained (Fig. 8), and from this curve the coefficient of conductivity from iron to air enclosed in a case is found, as in Test I., and tabulated in Table IV.

TABLE IV.

Iron in Case—Air Cooling.

Total Watts Dissipated.	Mean Temperature Rise of Iron. ° C.	Coefficient of Conductivity C.	Resistance to Heat Flow $R = \frac{1}{C}$.
19·0	20	$1·125 \times 10^{-3}$	890
30·0	30	$1·184 \times 10^{-3}$	845
41·6	40	$1·232 \times 10^{-3}$	812
54·5	50	$1·291 \times 10^{-3}$	775
68·3	60	$1·348 \times 10^{-3}$	742
79·5	67	$1·405 \times 10^{-3}$	712

In Fig. 9 the conductivity coefficient is plotted against the mean temperature rise of the iron, and is practically a straight line, so that the conductivity is a linear function of the final temperature rise, and therefore the watt-temperature curve is parabolic. As in the case of iron exposed freely to the air (Test I.), by producing this curve to cut the axis at $T=0$, we have $C = 10·1 \times 10^{-4}$, being practically the same

as for $T = 0$ in Test I.—viz., $10{\cdot}75 \times 10^{-4}$—and as the calculated value $10{\cdot}275 \times 10^{-4}$. The equation connecting C and T in Fig. 9 is—

$$C = 10{\cdot}1 \times 10^{-4} + 0{\cdot}05\ 10^{-4}\ T$$
$$= 10^{-3}\ (1 + 0{\cdot}005\ T)\ \text{nearly.}$$

Let σ be the watts dissipated per sq. cm. of iron surface, then $\sigma = 10^{-3}$ $(T + 0{\cdot}005\ T^2)$, from which $T = 100\left\{\sqrt{1 + 20\,\sigma} - 1\right\}$.

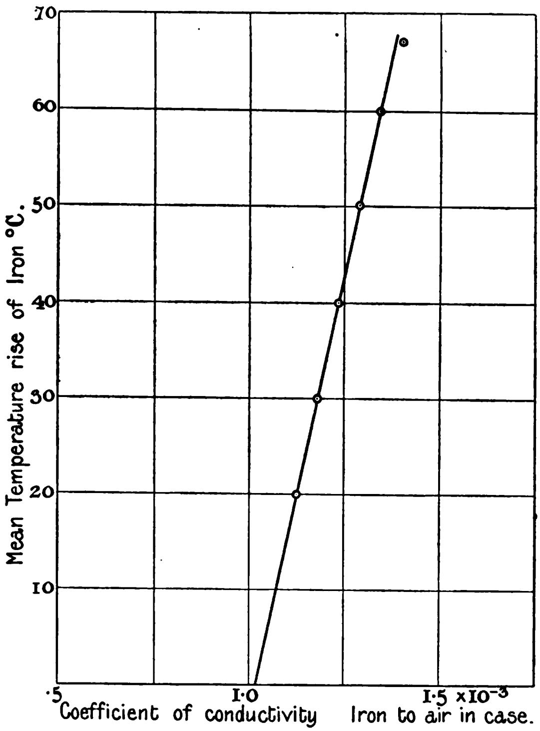


FIG. 9.

Watts Dissipated.	Calculated Temperature Rise.	Experimental Temperature Rise.
20	21·4	21·0
40	39·6	38·8
60	55·5	54·2
80	70·0	67·2

This formula therefore gives the rise in temperature of the iron in terms of the total watts dissipated, and the total surface, for iron enclosed in the case.

To test the formula, the temperature rise has been calculated and compared with the test values.

Rise in Temperature of the Air Flowing up the Iron Surface.—The arrangement for measuring the air temperatures has already been described, the eight thermo-couples shown in Figs. 1 and 2 being used for the purpose.

The following are the final air temperatures, above-room temperature, corresponding to some of the iron temperatures of Test II.:—

Temperature Rise of Iron.		Temperature Rises Registered by Thermo-couples.							
Top.	Bottom.	1.	2.	3.	4.	5.	6.	7.	8.
69·0	60	27·0	26·0	23·5	22·6	33·5	33·0	24·5	23·5
56·0	47	22·5	21·5	19·2	18·5	28·0	27·5	21·5	19·5
42·3	35	17·0	16·4	14·5	13·9	21·5	21·5	16·0	14·8

The various temperatures for the first row of figures are represented in Fig. 10, and are typical of the others. It will be seen that the temperatures at couples 5 and 6 are practically equal, and also at couples 7 and 8. Between 6 and 7 there is a large drop in temperature. This also applies to the lower couples Nos. 1, 2, 3, 4. This led to the belief that the temperatures assumed by the couples was largely influenced by the temperature of the brass sheet holding them in position, notwithstanding that they were separated from the brass by glass tubes, and that the thermo-junction was about 1 cm. distant from it. The heat was conducted from the hot-iron stampings through the brass sheet to couples 1, 2, and 5, 6, but was stopped by the air-gap between 2, 3, and 6, 7, hence the reason for the temperatures shown in Fig. 10. To remedy this, the brass was replaced by an ebonite couple holder of similar shape. The coefficient of conduction of ebonite being only about $\frac{1}{800}$ that of brass (Landholt and Börnstein), any effect on the couples by conduction is negligible. Some of the tests in Test II. were now repeated with the results given on page 773.

Each of these is represented in Figs. 11A, 11B, 11C, and shows a continuous curve of temperature drop down the air, the fall being very rapid near the iron, and becoming less steep as the distance from the iron increases. This sudden drop in temperature between the iron and couples 1 and 5 shows that the heat flow experiences a high resistance in passing from the iron to the air—that is, at the surface of the contact. This is, no doubt, partly due to the relative molecular densities of the

iron and air. The number of molecules in a lamina of unit area in the air is very much less than for the iron, so that the heat passes from the

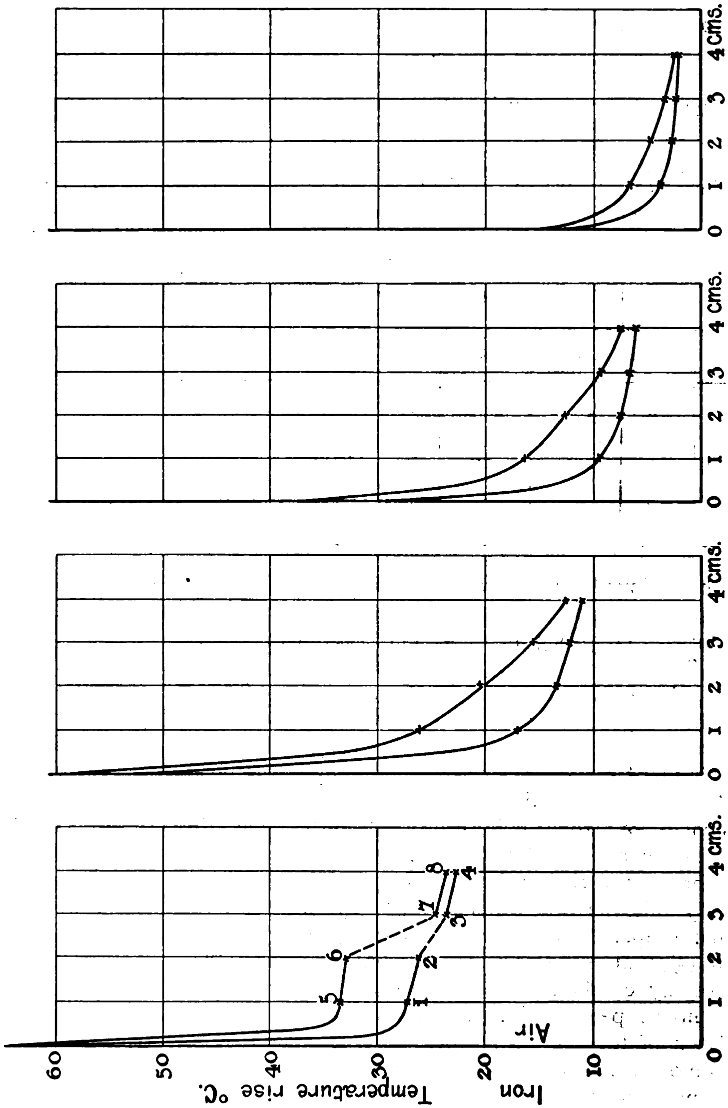


FIG. 11C.

FIG. 11B.

FIG. 11A.

FIG. 10

iron to the air only with difficulty—that is, there must be a large temperature drop from iron to air. With oil as the cooling medium the contact will be much better than for air, therefore we should expect

the temperature drop at the surface to be less than for air. This is actually found to be the case. In the figures given above for air the temperature of the iron at the bottom is always about three times that

Temperature Rise of Iron.		Temperature Rises Registered by Thermo-couples.							
Top.	Bottom.	1.	2.	3.	4.	5.	6.	7.	8.
58·0	51·0	17·0	13·25	12·0	11	26·20	20·5	15·50	12·5
36·0	29·5	9·5	7·50	6·8	6	16·25	12·7	9·25	7·5
14·2	12·8	3·8	2·80	2·4	2	6·70	4·9	3·20	2·5

at nearest couple—*i.e.*, No. 1, and at the top is about twice that of couple No. 5. For oil cooling these values are 1·6 and 1·7 respectively (Test IV.).

Test IIa.

In this test everything was the same as in Test II., except that the separating sheet was inserted midway between the iron and the case, as shown in Figs. 1 and 2. The object of this sheet is to assist the cooling by aiding convection, the heated air flowing up between the hot iron and sheet, and flowing down between the sheet and cool case.

The results of this test are given in Table V.

Table V.

Iron enclosed in Case—Air-cooling—with Separating Sheet.

Room Temperature, °C.	Final Temperature Rise of Iron at—			Mean Temperature Rise.	Watts Dissipated.
	Top.	Middle.	Bottom.		
14·6	70·0	72·0	59·5	67·2	57
13·0	55·8	57·5	47·0	53·4	44
14·0	50·5	52·0	43·7	48·7	39
14·5	36·0	37·1	30·5	34·4	27

The temperature rise is plotted against watts dissipated in Fig. 12, and shows a large increase in temperature over those for Test II., instead of a decrease, as was anticipated. This is probably due to the reflection of the radiant heat back on to the iron, and also to a small

extent to the resistance at the new surface to the escape of heat by conduction. These results therefore show that the insertion of a separating sheet, although no doubt assisting convection currents, is not, on the whole, a useful cooling agent.

TEST III.

Iron Cooled by Air Blasts.—In this test, blasts of air of different intensities were blown through the case. The central plate at the

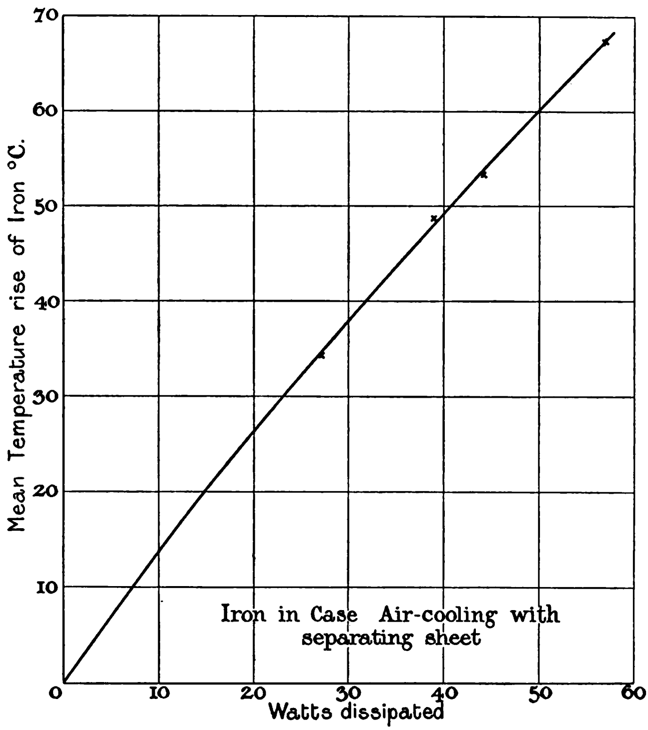


FIG. 12.

bottom of the case was removed, and the whole placed upon a box-like structure having a small electric fan in front. The fan was provided with a series resistance giving three speeds. The supply of air was measured by an anemometer placed over the hole at the top of case, and the rise in temperature of the blast was measured by thermometers placed at the entrance and exit. Some difficulty was experienced in keeping the air blast constant, as the fan supply volts varied slightly. The watts carried away by the air has been calculated from the anemometer readings, taking the specific heat of air as 0·238 calories per

gramme-degree, and weight of air at 15° C. as 1·188 grammes per litre. In all cases this calculated value agrees fairly well with the watts input to apparatus, showing that the anemometer was tolerably accurate.

The results of the tests are given below :—

TABLE VI.

Lowest Speed of Fan.

Room Tempera-ture. °C.	Mean Final Rise of Iron.	Cubic Feet of Air per Hour.	Temperature of Air at Exit.	Rise of Air Tempera-ture.	Watts Carried Away by Air.	Watts. Input.
15·3	53·7	950	25·2	9·9	86·0	90·0
14·7	43·8	1,000	22·0	7·3	66·5	70·0
15·2	32·6	980	20·3	5·1	45·4	50·5
15·0	20·5	980	18·0	3·0	27·0	31·0
Intermediate Speed of Fan.						
15·2	54·7	1,500	23·3	8·1	110·0	105·0
14·9	44·5	1,450	21·2	6·3	83·0	80·0
14·9	35·4	1,435	20·0	5·1	66·5	62·5
14·7	25·1	1,385	18·2	3·5	43·0	44·5
Highest Speed of Fan.						
14·8	47·3	1,700	20·5	5·7	91·0	95·0
15·0	39·0	1,680	20·1	5·1	79·5	82·5
13·2	31·9	1,800	16·7	3·5	59·0	65·0
14·3	21·7	1,650	16·9	2·6	40·0	43·0

The watt-temperature curves for the three tests are shown in Fig. 13, and may be taken as straight lines. The value of the conductivity coefficient C will therefore be constant. From Fig 13 these are found to be—

C.	$R = \frac{1}{C}$.
$1·90 \times 10^{-3}$	525 for lowest blast.
$2·14 \times 10^{-3}$	470 for intermediate blast.
$2·42 \times 10^{-3}$	415 for highest blast.

The temperature attained by the iron when cooled by an air blast will depend upon four main factors :—

1. The volume of the blast per unit of time.
2. The velocity of the air.

This will depend upon the volume of blast and upon the sectional area of its path, *i.e.*, the dimensions of the apparatus and case. If the area is large and the volume of blast of medium value, then the velocity may be reduced to the order of that of convection currents, in which case the cooling will be similar to that of Test I., where the iron was exposed freely to the air.

3. The temperature of the ingoing blast.
4. The direction of the air blast with respect to the surface of the iron.

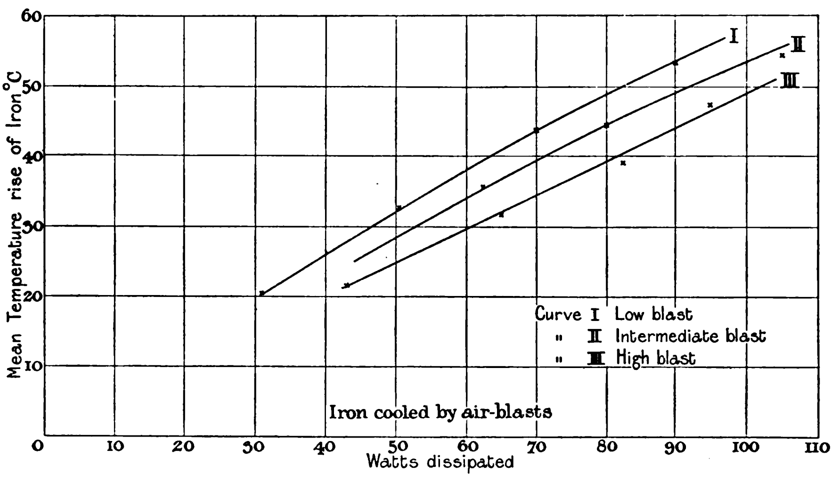


FIG. 13.

The iron will be cooled more effectively if the cold air impinges normally upon its surface than if it flows parallel to the surface, for not only will the contact between the air and iron be better in the former case, but the agitation of the air will be much greater, thus bringing a constant stream of cold air against the iron. For these reasons it is impossible to generalise to any extent upon the results of this test. The curves of Fig. 13, however, show that cooling by air-blast is very effective, especially considering that the ratio of the volumes of the blasts is only 1 : 1·4 : 1·7.

The Oil Cooling of Iron Stampings.—Owing to the high value of the coefficient of heat conduction of oil in comparison with that of air an oil-cooled transformer has a much larger output than that of an air-

cooled transformer. Oil cooling is therefore more economical than air cooling, since the amount of material in the transformer is less for the same output. Another advantage attending the use of oil is due to its high specific heat. The energy loss in the transformer is absorbed by the oil, whose temperature rises slowly. Hence when working intermittently, for instance, during the day only, the transformer may never reach its steady final temperature corresponding to the watts lost. The high specific heat of the oil also allows of the transformer being worked at a high overload for a considerable time without overheating. Other advantages of oil over air are :—

1. The high insulating properties of oil.
2. Its high dielectric strength, this being about five times that of air.
3. The prevention of particles of dirt and moisture getting into the windings. These have a very detrimental effect upon the insulation of the transformer, especially if working on high-tension circuits.

Tests similar to those already described were now made, using oil as the cooling medium.

The oil was best transformer oil supplied by the Vacuum Oil Company. Its specific gravity was 0·84, and its specific heat as determined by the method of mixtures was about 0·5 calories/gramme,° this being taken from two results—viz., 0·51 and 0·518.

Test IV.

The case was filled to a height of 11 cms. above the upper wooden disc of the apparatus, Fig. 1, about 3½ gallons of oil being used. As in the preceding tests, the initial heating was performed with a large current by cutting out the main current regulator. When a satis-

Table VII.

Oil Cooling.

Room Temperature. °C.	Temperature Rise of Iron.			Mean Rise. °C.	Watts Dissipated.
	Top.	Middle.	Bottom.		
14·2	40·25	36·7	30·7	35·9	115
15·0	33·50	30·5	25·5	30·0	95
15·1	28·50	26·0	22·0	25·5	80
14·9	18·00	16·5	13·5	16·0	47

factory temperature had been reached the watts were reduced to approximately the correct value, and readings taken until the temperatures became constant. Even then several hours were usually taken before the final temperatures were reached.

TABLE VIII.

Temperature Rise of Iron.		Temperature Rise of Couples in Oil.								Temperature of Case.			Mean of Case.
Top.	Bottom.	1.	2.	3.	4.	5.	6.	7.	8.	Top.	Middle.	Bottom	
40·25	30·7	18·40	18·40	18·6	18·6	26·0	26·0	25·9	25·2	16·6	16·30	10·4	14·40
33·50	25·5	15·20	15·20	15·4	15·4	21·5	21·5	21·5	21·0	13·8	12·70	7·2	11·25
28·50	22·0	12·25	12·25	12·3	12·3	17·9	17·9	17·9	17·2	11·1	10·25	5·8	9·00
18·00	13·5	7·00	7·00	7·0	6·8	11·0	11·0	11·0	10·3	6·6	6·20	3·6	5·50

The temperature rise of the oil was measured by couples 1 to 8, and that of the case by three couples placed at the top, middle, and bottom respectively. The results of this test are given in Tables VII. and VIII.

In Fig. 14 the mean temperature rises of the iron and case are plotted against the total watts dissipated. The points lie evenly about

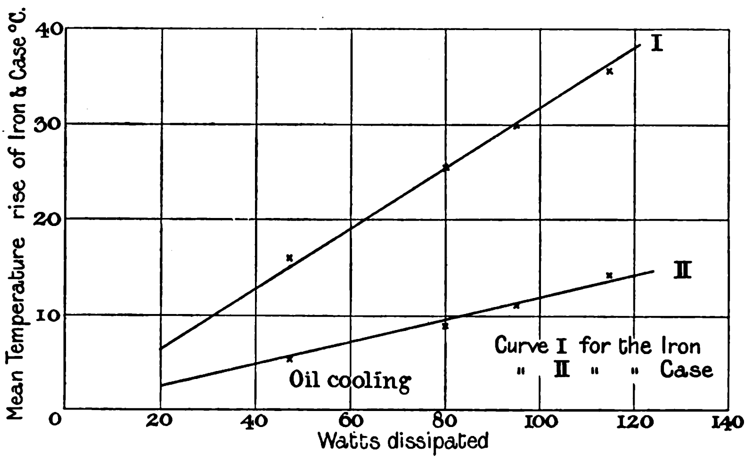


FIG. 14.

a straight line showing that up to the temperatures obtained in the test the final temperature rise is proportional to the energy

loss, that is, the value of the conductivity coefficient C in $C = \frac{\sigma}{T}$ is constant, where, as before, σ is the watts lost per sq. cm. of surface, and T is the temperature rise. The iron surface is 845 sq. cms. exposed to the oil, and from Fig. 14 we have $\frac{W}{T} = 3{\cdot}15$ approximately, therefore ${}_{i}C_{a} = 3{\cdot}75 \times 10^{-3}$ from iron to external air. This is about three times the value found for C in Test II., where the iron was cooled by air only, and therefore shows clearly the very great superiority of oil as a cooling medium.

The temperatures assumed by the oil are interesting. Fig. 15

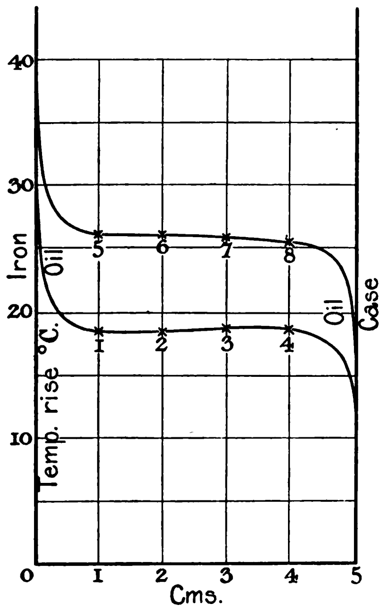


FIG. 15.

shows the temperature gradient from the iron to the case through the oil for the first values in Table VIII. and is characteristic of the others. As with air cooling there is a large temperature drop between the iron and the oil at the surface, although not so marked as in air cooling. This point will be further dealt with shortly. The drop in temperature down the oil at the top of the iron is very slight. This is not only due to the good conduction coefficient of the oil, but also to the fact that the hotter oil near the iron is in motion and mixes with the cooler oil at the case, so giving an almost uniform temperature horizontally. At the bottom of the iron the oil temperature at the two couples nearest the case is slightly higher than at those nearest the

iron. This is due to convection, some of the hot oil at the top sinking as it is cooled by the case and displacing cold oil from the bottom which flows past couples 1 and 2. Between the oil and case there is always a large temperature drop similar to that between the iron and oil. From Fig. 14 it appears that the final mean temperature of the case is proportional to that of the iron, the temperature rise of the iron being roughly $2\frac{1}{2}$ times that of the case.

In Fig. 16 the temperature rises of the oil nearest the iron—viz., at couples 1 and 5 are plotted against the temperature rise of the iron at the bottom and top respectively. These points may be taken to lie upon straight lines. The ratio of the iron temperature at the top to that of the oil in contact with it is about 1·6, and at the bottom is 1·7, or we may say that the ratio of the mean temperature rise of the iron to that of the oil is 1·65. If T_i represent the mean temperature

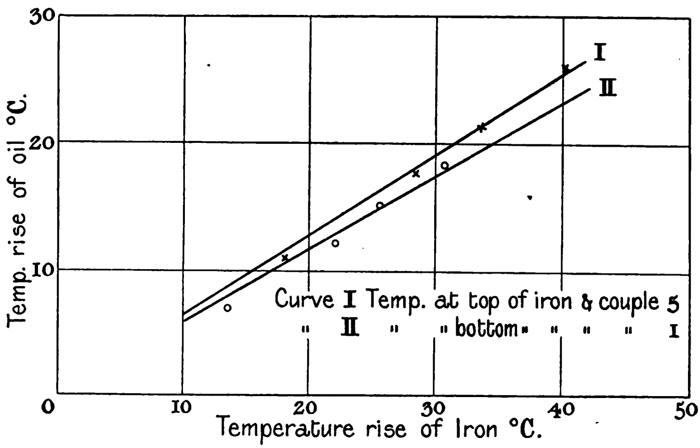


FIG. 16.

rise of the iron, and T_o that of the oil, then $T_i = 1{\cdot}65\, T_o$. If S be the area of the iron exposed to the oil, and W the total watts passing as heat to the oil, then ${}_iC_o = \dfrac{W}{S(T_i - T_o)}$ from iron to oil.

$$\therefore {}_iC_o = \frac{2{\cdot}5\, W}{S\, T_i} = 2{\cdot}5 \times 3{\cdot}75 \,.\, 10^{-3} = 9{\cdot}4 \times 10^{-3}.$$

In the same way we have ${}_oC_c$, the conductivity from the oil to case is—

$${}_oC_c = \frac{W}{S\,(T_o - T_c)}$$

where T_c is the temperature rise of case, and S is the area of the case in contact with the oil. As it is very probable that the oil underneath the apparatus remained practically at atmospheric temperature throughout the test, the area of the bottom of the case may be neglected.

Taking only the vertical sides of the case in contact with the oil we have $S = 3{,}000$ sq. cms. From the given values of the temperature of the oil at the case we obtain $\frac{T_o}{T_c} = 1{\cdot}53$, and putting $\frac{T_i}{T_o} = 1{\cdot}65$—

$$ {}_oC_c = 5 \times 10^{-3}. $$

Lastly, if S_c be the surface of the case, and T_c its temperature rise, then the conductivity coefficient from case to air is—

$$ {}_cC_a = \frac{W}{S_c\, T_c}. $$

From Fig. 14—

$$ \frac{W}{T_c} = 8{\cdot}4. $$

A difficulty arises in assigning a value to the effective area of the case. The bottom may be neglected as its temperature never rises appreciably, and it will usually be in contact with a bad conductor of heat. The top being horizontal will not lose so much heat by convection as a vertical surface, but will be an effective radiator. We may, as an approximation, take half its area as its effective surface, and add this to the vertical surface. The total surface is then roughly 5,000 sq. cms., from which ${}_cC_a = 1{\cdot}7 \times 10^{-3}$.

Test IVa.

This test is a repetition of Test IV., but with the separating sheet put in as in Test IIa. The results of Test IIa. showed that this sheet was a distinct failure as an agent in cooling the iron in air.

The results of the test are given below in Table IX.

Table IX.

Oil Cooling, with Separating Sheet.

Room Temperature. °C.	Temperature Rise of Iron.			Mean Rise. °C.	Watts Dissipated.
	Top.	Middle.	Bottom.		
14·6	37·0	34·0	29·0	33·3	110
14·6	29·5	26·5	22·0	26·0	90
14·7	23·6	21·7	18·3	21·2	62
14·6	18·80	17·2	14·6	16·8	48

The watt temperature curve for this case is shown in Fig. 17 in the full line. The broken line represents the corresponding curve for

Test IV. without the sheet (Fig. 14). It will be seen that the two curves cross at a temperature rise of 25° C.

Below this temperature the effect of the sheet is to increase the temperature rise of the iron. This is probably due to the shielding effect of the sheet noticed in Test IIA. Above 25° the sheet exerts a cooling effect upon the iron. This is the result of the additional circulation of the oil, which takes place with the sheet dividing the oil into two separate portions. Hence at 25° rise the tendency of the sheet to stop the flow of heat through the oil, and the reflection of the radiant heat is counterbalanced by the increase in the circulation. Above that temperature the circulation predominates, and below it the screening effect predominates.

The temperatures registered by the couples in the oil and case, corresponding to the figures in Table IX., are given in Table X.

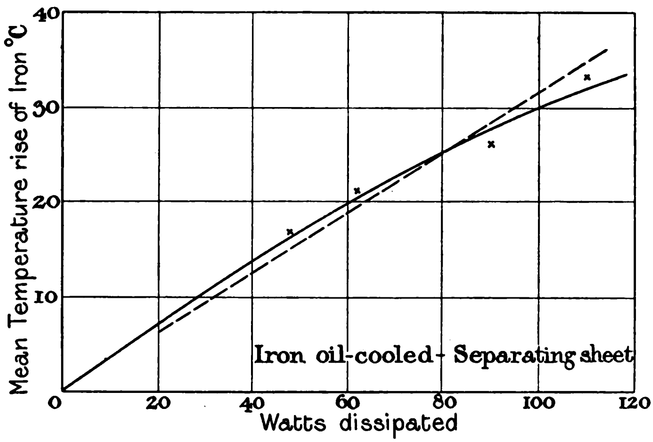


FIG. 17.

From these figures it will be seen that couples 3 and 4 exhibit a higher temperature than couples 1 and 2 in every case. This is much more marked than in Test IV., without the separating sheet, and shows the increase in the circulation of the oil due to the sheet. The flow of the oil and its temperatures, at different points in its path, may be followed by noting the temperatures of the pairs of couples at any given time. For instance, in Table X. the highest temperature of the oil is at the top of the iron, that is, at couples 5 and 6. The oil then flows over the top of the sheet and down to couples 7 and 8, whose temperature is next in value to that at 5 and 6. The next temperature in order is that at the lower outer couples 3 and 4, and the lowest is at the bottom of the iron, *i.e.*, 1 and 2. These have been plotted in Fig. 18 for the first row of figures of Table X.

By plotting a curve similar to Fig. 16, that is, the temperature rises of the oil at couples 5 and 1, against that of the iron at the top and

TABLE X.

Oil Cooling, with Separating Sheet in.

Temperature Rise of Iron. °C.		Temperature Rise of Oil at Couples.								Case.			Case. Mean.
Top.	Bottom.	1.	2.	3.	4.	5.	6.	7.	8.	Top.	Middle.	Bottom.	
37·0	29·0	17·6	18·0	20·2	20·0	24·20	24·2	23·4	22·8	15·2	14·80	8·20	12·7
29·5	22·0	12·8	11·7	13·0	12·8	17·20	17·2	16·3	15·8	10·2	9·75	6·15	8·7
23·6	18·3	10·4	10·8	11·6	11·5	14·75	14·6	14·1	13·6	8·6	8·10	4·70	7·1
18·8	14·6	8·2	8·3	8·9	8·8	11·40	11·4	10·9	10·5	7·2	7·00	4·40	6·2

bottom respectively, two curves which are practically superposed are obtained, and, moreover, lie between curves I. and II. in Fig. 16, so

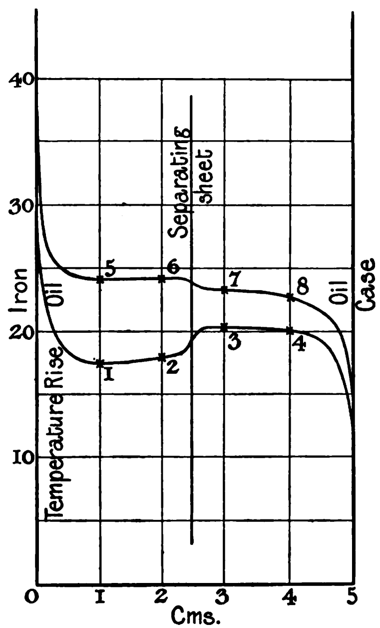


FIG. 18.

that the ratio between the temperatures of the iron and the adjacent oil is the same as before, viz., 1·65.

Also, by plotting a curve for the temperature of the case against the

watts dissipated, as in Fig. 14, the curve is practically that given in Fig. 14. This follows from the fact that, if the same watts are to be dissipated from the case, its mean temperature rise above the air must be the same as before.

TEST IVB.

As the result of Test IV. values were given to the conductivity coefficients between the various surfaces obstructing the heat flow from the iron stampings to the external air.

It is unnecessary to say that these are not absolutely definite values

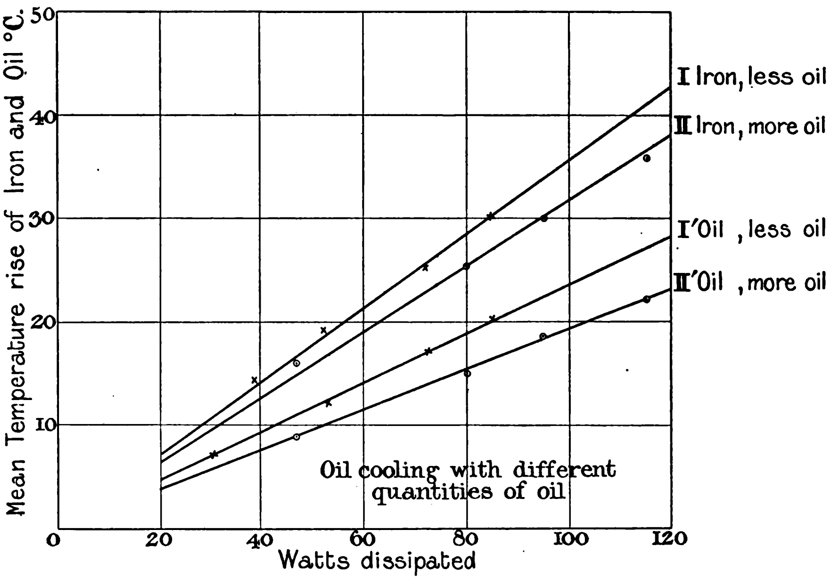


FIG. 19.

under all circumstances, but must alter slightly with varying conditions. One such variable is the quantity of oil in the case.

The conductivity coefficient from the oil to the case has been given as—

$$ {}_oC_c = \frac{W}{S\,(T_o - T_c)}, $$

where—

W = total watts dissipated as heat.
S = surface of case in contact with oil.
T_o and T_c = temperature rises of oil and case respectively.

Now if S be decreased, by reducing the quantity of oil, the watts remaining constant, and we suppose the value of ${}_oC_c$ to remain approximately constant, then the temperature difference $(T_o - T_c)$

increases. Now T_c must be constant, since the case is dissipating the same watts as before, hence T_o, the temperature rise of the oil, increases, and so $\frac{T}{T_c}$ increases. At the surface of the iron we have—

$$(T_i - T_o) = \frac{W}{{}_iC_o S}.$$

The exposed surface S of the iron is unaltered, hence $(T_i - T_o)$ is constant for a constant loss W. But as T_o has increased, T_i, the temperature rise of the iron, increases, and $\frac{T_i}{T_o}$ decreases.

To find if this actually occurred, the level of the oil was reduced almost to the top of the iron.

The results obtained are given in Table XI.

TABLE XI.

Room Temperature. °C.	Temperature Rise of Iron.			Mean Rise. °C.	Watts Dissipated.
	Top.	Middle.	Bottom.		
15·2	34·5	31·0	25·5	30·3	85·0
14·6	29·0	26·0	21·5	25·5	72·0
15·1	21·8	19·6	16·0	19·1	52·5
15·0	16·0	15·4	12·0	14·5	39·0

The watt-temperature curve plotted from these values lies above that for Test IV., Fig. 14, so that for the same watts, the temperature of the iron rises as the quantity of oil diminishes. In Fig. 19, curve I. is for the above values, and curve II. is Fig. 14 reproduced. The temperatures of the oil and case for this test are given in Table XII.

TABLE XII.

Temperature of Iron. °C.		Temperature Rise of Couples.								Case.			Case. Mean.
Top.	Bottom.	1.	2.	3.	4.	5.	6.	7.	8.	Top.	Middle.	Bottom.	
34·5	25·5	15·4	15·5	15·80	15·80	25·2	25·2	25·2	24·6	11·0	12·0	7·0	10·0
29·0	21·5	13·0	13·1	13·30	13·30	21·0	21·0	21·0	20·5	10·0	10·0	6·0	8·7
21·8	16·0	9·2	9·2	9·25	9·25	15·8	15·8	15·6	15·2	7·0	7·1	4·0	6·0
16·0	12·0	7·4	7·4	7·45	7·45	12·0	12·0	12·0	11·6	4·7	4·8	2·5	4·0

From these figures curves may be plotted of the temperatures of the iron and adjacent oil as in Fig. 16, from which is found $\frac{T_i}{T_o}$ at top of iron $= 1{\cdot}65$ and at bottom $= 1{\cdot}37$, or mean value of $\frac{T_i}{T_o} = 1{\cdot}5$.

In Tests IV. and IVA. this was found to be 1·65, therefore, as was expected, $\frac{T_i}{T_o}$ decreases as the amount of oil decreases.

In Fig. 19, curves I′. and II′. are the mean temperatures of the oil corresponding to the iron temperature curves I. and II. From these it is evident that $(T_i - T_o)$ is very nearly a constant for a given value of W, as was anticipated, and therefore the value of ${}_iC_o$ from iron to oil is the same for both tests, viz., $9{\cdot}4 \times 10^{-3}$. The temperature rise of the case also tallies approximately with that for Test IV. given in Fig. 14. The value of $\frac{T_o}{T_c}$ as derived from this test is 2·0, T_o being the mean value of couples 4 and 8 nearest the case, and T_c the temperature rise of the case.

In Test IV. this value was 1·53, so that $\frac{T_o}{T_c}$ increases as the oil decreases. It has been shown that this should be so.

Using this value of $\frac{T_o}{T_c}$ to find ${}_oC_c$ from oil to case the values become ${}_oC_c = 4{\cdot}3 \times 10^{-3}$, which is sensibly the same as found with the larger quantity of oil, viz., 5×10^{-3}. The surface in contact with the oil in this test was nearly 2,000 sq. cms. The value of ${}_cC_a$ from case to air will remain the same in Test IV., viz., $1{\cdot}7 \times 10^{-3}$, as the watt-temperature curves of the case for both tests nearly agree.

Test V.

Oil Cooling, assisted by Water Worm.—In this test a coil of lead pipe was submerged in the oil above the apparatus, with the object of cooling the oil by passing a stream of cold water through the coil.

The length of piping used was 28 ft., its internal and external diameters being respectively $\frac{5}{16}$ in. and $\frac{7}{16}$ in. The smaller the diameter of the pipe, consistent with allowing sufficient water to pass, the more effective will be the cooling, as more surface is exposed to the oil for the same total cross-section of the cooling worm. The quantity of water supplied was measured by collecting it in a tank placed on a weighbridge. The supply was kept as nearly as possible constant at about 200 lbs. per hour corresponding to a velocity of 1·65 ft., or 0·5 metres per second in the worm. The temperatures of the ingoing and outgoing water were measured by thermo-couples placed inside the pipe. The temperature of the oil at various parts in the neighbourhood of the water worm was also measured. The results of this test are shown in the table on next page.

The power was not reduced below 90 watts as the temperature rise

of the iron was already very low. The iron loss could not be raised above 120 watts without going beyond the limits of the wattmeter, and owing to lack of time it was impossible to make and calibrate new resistances for the purpose of reading higher inputs.

TABLE XIII.

Oil Cooling with Water Worm.

Room Temperature °C.	Mean Rise of Iron. °C.	Temperature of Oil at Worm. °C.	Water Supply in lbs./hr.	Temperature of Cold Water Supply.	Temperature Rise of Water.	Watts Input to Iron.
16·7	16·5	21·0	196	13·0	1°C.	115
15·0	14·0	20·2	198	13·5	0·8	90

The above results, however, are sufficient to show how exceedingly effective this method of cooling is, as the water rapidly absorbs the heat from the oil without rising greatly in temperature, due to its high specific heat.

The calculated values of the watts carried away by the water are 102 and 83·5 respectively, or about 90 per cent. of the watts dissipated by the iron pass into the water. The surface of the coil exposed to the oil was about 3,000 sq. cms.

If T_o be the temperature of the oil outside the coil, T_w the mean temperature of the water, W the watts passing into the water, and S the surface of the coil, then ${}_oC_w = \frac{W}{S(T_o - T_w)}$.

$$\left.\begin{array}{l}\text{In the first case } {}_oC_w = 4{\cdot}55 \times 10^{-3} \\ \text{In the second case } {}_oC_w = 4{\cdot}46 \times 10^{-3}\end{array}\right\} \text{ from Table XIII.}$$

We therefore find the coefficient of conductivity from oil to water through the thin metal pipe is about ${}_oC_w = 4{\cdot}5 \times 10^{-3}$.

SUMMARY OF RESEARCH.

The main conclusions to be drawn from the foregoing tests may be summarised briefly. By far the most effective method of cooling transformers is that of oil cooling, assisted by the circulation of cold water through a coil of pipes immersed in the oil.

As the water absorbs a high percentage of the total energy loss, it is unnecessary to provide a case with a large cooling surface. This method should, therefore, be adopted for large transformers when there is a good supply of cold water available. If this is not available the same water can be used continuously with the use of an outside cooling arrangement and a circulating pump. If, owing to a temporary breakdown of the pump, the water supply is stopped, no great danger

need be apprehended, as the enormous thermal capacity of the oil and the water in the coil prevents any large rise in temperature for a considerable time.

On no account should a joint be made in the coils inside the case, as this leads to a liability to leakage, the slightest trace of moisture in the oil reducing its dielectric strength very considerably.

With regard to unassisted oil cooling, this is much more effective than any type of air cooling, as the conductivity of iron to oil is so much greater than to air.

Dealing with the use of the separating sheet to assist the cooling of the transformer, it is very probable that more satisfactory results would have been obtained if the surface of the sheet had been of a dull black nature instead of the comparatively bright brass used, as a dull black surface is a worse reflector of heat than a bright surface.

Condition of Cooling.	Coefficient of Conductivity.	Coefficient of Resistance.
Iron free in air ...	$1{\cdot}3 \times 10^{-3}$ to 2×10^{-3} for temperature rises of 20° to 60° C.	770 to 500
Iron enclosed in case	$1{\cdot}125 \times 10^{-3}$ to $1{\cdot}35 \times 10^{-3}$ for rises of 20° to 60° C. ...	900 to 740
Iron cooled by air blast	$1{\cdot}9 \times 10^{-3}$ to $2{\cdot}4 \times 10^{-3}$ depending upon volume of blast	525 to 410
Oil Cooling.		
Iron to oil	$9{\cdot}4 \times 10^{-3}$	106
Oil to case	$4{\cdot}5 \times 10^{-3}$	220
Case to air	$1{\cdot}7 \times 10^{-3}$	600
Oil to water through metal piping ...	$4{\cdot}5 \times 10^{-3}$	220

The cooling by air blast, although effective, necessitates the use of blowers and air filters, and further, if for any reason the blast be stopped, the temperature of the transformer will quickly rise to a dangerous degree.

Natural cooling in air is simple and economical, but this method can only be applied to transformers of small size, as the energy loss, for the same induction and frequency, is proportional to the cube of the linear dimensions, whereas the cooling surface is only proportional to the second power, and therefore the heat to be dissipated per sq. cm. of surface rises rapidly with increase in size, producing a higher temperature rise of the transformer.

The various values of the coefficient of conductivity obtained in the tests may be recapitulated. The coefficient of resistance is also given, this figure being better for purposes of rapid comparison than the coefficient of conductivity.

The watt temperature curves for all the Tests I. to V. are plotted in Fig. 20, and show the comparative efficiencies of the various methods of cooling the iron.

The above work has only dealt with the cooling of the iron core of

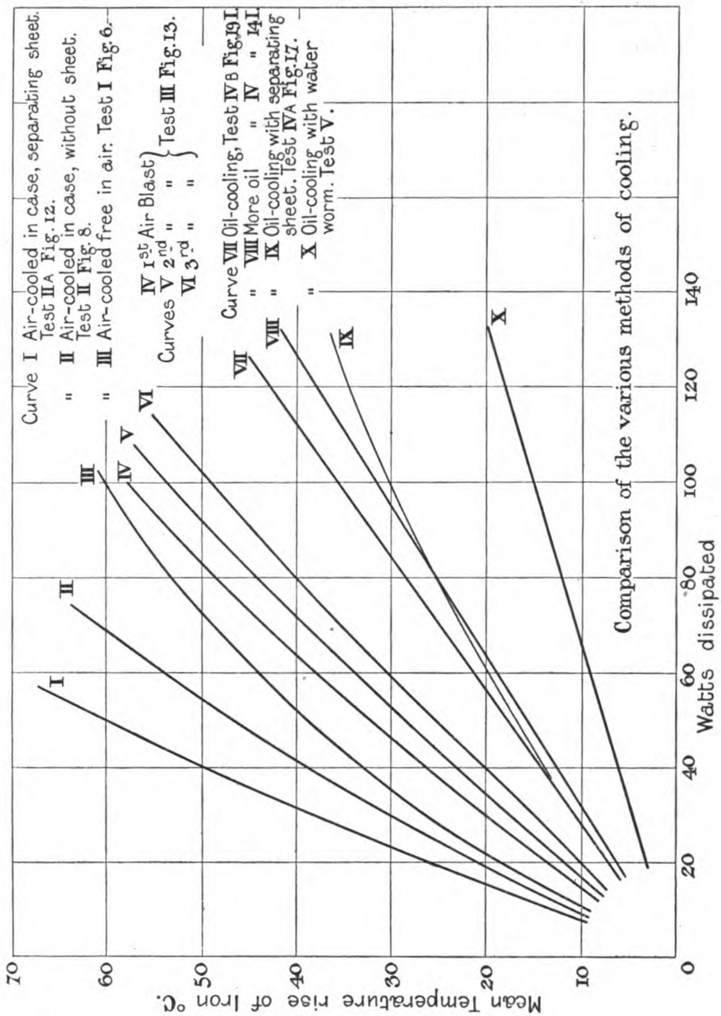


FIG. 20.

transformers. A considerable amount of heat, however, about equal to that of the iron loss, is contributed by its windings. A similar research to the above might therefore be conducted with the object of determining the conductivity coefficients for various types of coils—concen-

tric and sandwiched—under similar conditions of cooling to those employed in this research.

In conclusion, I have to thank Professor Kapp, at whose suggestion the research was carried out, for the facilities afforded me, and also the engineering staff of the University of Birmingham for permission to use some of the apparatus required in the tests.

Discussion.

Dr. Kapp.

Dr. G. Kapp: I must compliment Mr. Gifford on an exceedingly careful and painstaking piece of scientific investigation. The results will be of value to transformer designers. I do not suggest that they have not already certain rules, because excellent transformers are designed, but every maker keeps his rules secret and will not tell how much cooling surface he provides nor the quantity of air or water required in the cooling worm. There is a method not mentioned by the author of cooling by water. The usual water worm should obviously be placed above the transformer, the case being made high enough to accommodate it. Owing to the large coefficient of expansion of oil there is a fairly vigorous oil circulation. But with all water worms there is a danger of the pipe scaling or getting furred by sediment if dirty water has to be used. The new method is to use an oil worm external to the transformer. It is connected to the top and bottom of the transformer case and is placed in any convenient position where there is cooling water. A suitably placed pump is provided which secures a vigorous circulation of the oil. The system has the advantage that it is immaterial whether the water is clean or dirty.

Dr. Garrard.

Dr. C. C. Garrard: With regard to the effect of the separating sheet I would have expected this to be much greater. It seems to me that the results have been masked by radiation. Cooling effects are greatly increased by providing openings in the windings through which air can pass, and are still further increased by increasing the speed of the air passing through these ducts. The paper might well be extended to discuss the question of cooling as it is carried on in different classes of transformers.

Mr. Gifford.

Mr. R. D. Gifford (*in reply*): In reply to Dr. Garrard's remarks, it is fairly evident from the results obtained by the use of the separating sheet that the circulation of the oil was considerably augmented, but this was overwhelmed by the combined efforts of the shielding of the radiant heat and the resistance offered to the conducted heat by the interposition of the new surface in its path, for in every case it was found that a very steep temperature gradient—*i.e.*, a high resistance—existed at the surface of the metal and the fluid cooling medium.

With reference to the general question of the cooling of transformers, I should say that there is such an enormous variety of types that it would have been quite impossible to have obtained results covering them all. In this connection I would point out that the paper (as its title denotes), does not pretend to deal with the heating of trans-

Mr. Gifford.

formers as a whole, but merely with the iron core. In a paper read before this Institution some two years ago by Mr. T. M. Barlow,* it was shown that the conductivity of iron stampings was about 100 times as great along them as across them, due to the small air ducts and insulation between each.

Therefore, in estimating the cooling surface of the core, only the edge surface of the stampings need be taken into account as was done in the tests described. Then if the core loss is known and the particulars of the case and method of cooling, the ultimate temperature rise can be found.

In reply to Dr. Kapp, I can only say that I did my best to carry out the work as carefully as possible and would again acknowledge my indebtedness to him for many suggestions during its progress.

* *Journal of the Institution of Electrical Engineers*, vol. 40, p. 601, 1908.

THE PRESENT ASPECT OF ELECTRIC LIGHTING.

By H. W. HANDCOCK and A. H. DYKES, Members.

(The paper, with the report of the discussions at London and at Birmingham, will be found on pp. 57–99.)

DISCUSSION AT THE MANCHESTER LOCAL SECTION ON FEBRUARY 22, 1910.

Mr. Atchison.

Mr. C. C. ATCHISON: The conditions in the paper are not in agreement with my experience. The author is dealing mainly with small alternating-current stations having a large lighting load, the day load only amounting to about 5 per cent. of the total income. In the North we like to have a good power load. I should be extremely sorry to find the income from my day load as low as 5 per cent. of my total income; in fact, I do not think I shall be satisfied unless it is decidedly more from power than from lighting. One looks forward to the reversal of the conditions in the paper, the generating station becoming a power station, with lighting as a subsidiary item or by-product. The paper is interesting in connection with manufacturing towns, where one has to deal with large numbers of cottages. In some towns there is a residential district with large houses where a consumer is willing and able to pay for his own wiring, but with small property we have to deal with the landlord, who, in Rochdale at all events, has an idea that gas is the best method for lighting, and does not take the slightest account of the electricity undertaking. Mr. Handcock seems to think that the wire lamp has done harm. As far as we are concerned, I am not much afraid that we shall lose on the lighting, at all events we do not find it so with those consumers we have at present, but I am inclined to think that this is mainly because the standard of lighting has been getting higher during the last few years, and as the metallic filament lamp gives the consumer more light for his money, he does not usually try to cut down his bill. Shops, it seems, have realised that good lighting is an advertisement, and they maintain the old bills in order to secure this advantage. There are some particulars giving the consumption of a 12-c.p. lamp as 15·6 units per annum. For eight years I took out particulars of the consumption of various classes of consumers on our mains, and I regret to say that private house-lighting consumers, with 8-c.p. lamps, averaged 7·6 units per 8-c.p. lamp; that was with carbon filament lamps. This is equal to about 11 units for a 12-c.p. lamp, and points at once to the fact that we are dealing with the large houses who instal a large number of lamps, the result agreeing with the statement in the paper that a smaller return is obtained from the large houses than from the small houses. In regard to the lump sum charged per annum and the small price per unit, it sounds

Mr. Atchison.

very nice to talk to a consumer about 0·5d. or 0·4d. per unit without mentioning the annual lump sum that he has to pay, but I am inclined to think that in many towns, although the low price per unit would be appreciated, the lump sum payment would prove a source of trouble. Regarding the supply being charged at so much per lamp and the checks that one gets in connection with water, one does not throw water away—there is no gain in it—and if the taps leak the inspector calls attention to this. There is, I am sure, a greater difficulty in checking waste of electricity than of water, but I think it will work itself out on the lines Mr. Handcock has given, the check being the cost of renewal of the lamps. If the supply authority sells lamps too dear, or takes any action on information thus obtained, the consumer will look out for somewhere to get the lamps without going to the supply undertaking; this will produce a market, and whether the lamp-holders be some trick type or not, if there is a market some one will lay themselves out to supply it. The cost of wiring is certainly difficult to deal with, because the supply undertaking is to a certain extent in the hands of the contractors, unless they have a department of their own. The contractor makes his money out of the number of points wired, and it is naturally to his benefit to put in as many as he can. The results of this I have seen in the lights being badly arranged and many more than necessary installed, the annual bill for supply being therefore greater. This can be rectified if consumers will only give the supply undertaking the opportunity of advising them, except, of course, when dealing with large firms to whom it is not material to put in a few lights more or less, but if they will go "on their own" they very often get an installation wired up with a larger number of points than necessary, and they get a heavier bill than anticipated. Regarding cost of services, the point has been mainly dealt with from the alternating-current side, but one has to look at the direct-current side as well. Some few months ago, after having for a long time tried to standardise service cables, etc., I found that the gain in putting in smaller services and cutting the cost of joint boxes and services would be very little, because when taking an underground service into a building, the cost of excavation, etc., is practically the total cost, and I found that by bringing down my service cable standards to about one-half the size there was not more than a couple of shillings saved, which hardly warranted arranging the extra stock of smaller cables, etc. If one can go into a row of buildings then there will certainly be some gain. I should like to see corporations take their supply in at one end, and the wiring contractor take his supply at that point and run right through the building. It would come out much cheaper. With reference to dusk-to-daylight supply, this answers under suitable conditions, but unluckily when I wanted to start it in a district with only a small commencing load, I had to supply a motor in the first week or two, which upset the arrangement, although the motor was only a small one. A single motor is quite sufficient to put a stop to limited supply hours.

Mr. Slacke. Mr. R. B. SLACKE: I was talking to a central station engineer to-day, and he said the cost of depreciation of a metal filament lamp was very high, amounting to about 1d. per unit, which increases the lighting bill. Consequently he thought that in many cases, instead of renewing a lamp at, say, 3s., the small consumer would probably get a new mantle instead, and thus gradually get back to gas. In connection with Mr. Atchison's remark regarding people who are used to gas and do not like giving it up, they say also that it warms the rooms. In the case of mills they do not like doing away with gas, particularly in the weaving sheds—they say that gas warms their mill and saves heating. I should like to know what the dividing line is between a small, and therefore comparatively long-hour consumer, and a large consumer. How many lights has the man who burns them sufficiently long to charge him on so much per lamp installed? If a larger house be charged on that basis and it has many lamps this will make the cost very high. There must be some falling curve of hours per lamp to lamps installed, and on some point on this curve must be the dividing line between the consumer who should be charged on the contract system and the consumer who should be charged per unit.

Mr. Wheelwright. Mr. P. P. WHEELWRIGHT: With further reference to Mr. Slacke's question as to the dividing line between the small and large consumer, I shall be obliged if the authors would give approximately the rent of a house where this contract demand system is likely to be financially successful for the corporation or supply company and the consumer. As a scheme it appears very sound on paper, but I think there are a great many things to be said against it. My opinion of cottage and small property lighting, after the experience of having had several cottages wired for trial purposes, is that with any system of charging trouble will arise sooner or later, due to the failure or breakage of the lamps. The tenant will then say that he cannot afford to replace the broken lamps when they cost him shillings, whereas gas mantles can be obtained for a few pence. On page 62 the authors speak in a most matter-of-fact manner about losing unremunerative consumers. Personally I find that the loss of a single consumer, whatever the cause, has very far-reaching results. Again, on page 63, the authors suggest the use of special lamp-holders to prevent the lamps being removed or exchanged for higher candle-power. I do not think in practice this would be found to be a workable procedure; in fact, I imagine that trouble would arise directly. I should like to know what sort of an agreement the authors propose to draw up for the signature of the prospective consumer, as, judging from the paper, it seems to me that there will have to be a number of "ifs" put into it to prevent the use of high candle-power lamps, wastage of electricity, empty property, etc. In the case of a consumer using too much electricity, and this having been checked by meter, what steps do the authors propose to take to prevent its continuance? On page 64 an excellent suggestion is made that subsidiary companies should be formed in the various districts to sell light, and not energy, on special terms either to the

landlords or tenants direct, the energy, of course, being obtained by the company from the corporation or supply company in bulk at a special rate. In a later paragraph on the same page dealing with the advent of the wire lamp the authors state, "At present what do we see? Half the electrical world counting their losses due to an invention which should have proved, and may yet prove, as great a benefit to the industry as it undoubtedly is to the consumer." I think that this statement is anything but correct, as it cannot rightly be thought that the corporations and supply companies are being ruined by the use of the wire lamp, judging from their financial position. The question of putting auto-transformers into houses deserves very careful consideration, but there are transformers on the market which, though cheap, will eventually become very inefficient, and again in certain cases which will always arise auto-transformers will bring about anything but the desired reductions. The authors speak about lighting in country districts and the running of electricity departments and companies on the line of "dusk-to-dawn" supply. I cannot think that this would ever be agreed to for long in any district, as it is the various uses of electricity, other than lighting, that appeal to and are being pushed before the public. In the last paragraph before the appendix the authors state that the charge might be made in connection with the use of the contract demand system on premises which are already wired but unoccupied. I grant it is a most excellent suggestion, but I doubt very much its ever succeeding, and taking Lancashire and the North of England there is no belief in payment in advance or for energy not utilised. My experience of the maximum demand system and the flat rate in a Lancashire town is shown by the following illustration: My corporation decided some six years ago to offer a flat rate for lighting as an alternative to the maximum demand system which had then been in force for some eight or ten years. The immediate result was that 40 consumers out of some 1,200 decided to keep on the demand system, whilst the others desired to change on to the flat rate, even when the cost was known to be slightly higher, this result being due to their having the satisfaction of understanding how the figures were obtained. Personally, taking the rates for lighting and power purposes, I am satisfied that the simpler the rate the more likely one is to get consumers. Mr. Wheelwright.

Mr. J. FRITH: I have spent this morning in analysing my three years' bills for electric lighting, and I will give the results. I have 32 lamps installed. They are not all metallic filaments, as I am on the 200-volt supply. However, they average out at 36½ watts per lamp. My total yearly bill is £6 5s., the units being almost exactly 400, which works out that I burn each lamp on an average 350 hours per annum. I pay 3s. 9d. per lamp per year, which is equivalent to 3s. 2d. for a 30-watt lamp. I should certainly object to a change of 12s. for 30-watt lamps per annum. Mr. Frith.

Mr. A. G. COOPER: With a small consumer the cost of connecting up is practically the same as for a large consumer, and to connect up Mr. Cooper

Mr. Cooper. half a dozen lights requires the same cable at the same cost as to supply 20 lights. I have in some cases got the builder to put in the electric light. He would put it in the best rooms. In that case we take the cable in at the first house and right through the cellars, putting on cut-outs at each house. The question was raised about supplying light in the same way as water. In the gravitation systems the water wasted costs nothing, but in the case of London it would make a difference because the water is pumped. I have seen engines at the Kent Water Supply which are stopped when the main gets to a certain pressure; they have an accumulator, of course, so in that case the water wasted entails cost of steam. In addition to this, there is a limit to the capacity of a reservoir, and if the consumption goes up the water costs more. With regard to metallic filament lamps, we still have difficulty in persuading people to undertake the cost of renewals. My own corporation strongly object to any system of going round and trying to get hold of gas consumers. In the South, as I know, there are far more companies in operation. Electric light has been acquired in many cases, and they are fighting a private company, which gives one a freer hand, but when these schemes come before the committee they often refuse to pass them.

Mr. Stewart. Mr. C. L. E. STEWART: In Lancashire we are not really accustomed to think of stations with purely lighting loads. The author has certainly carried me back to ten or twelve years ago when I used to live in the district he mentions. I think the remarks made by Mr. Frith much to the point with regard to the difference between London and Lancashire people. London people seem rather to like a new method of charging for current, but in Lancashire they like a flat rate. Speaking of the "dusk-to-dawn" system, about a year ago I had to start a small works, and thought I could run for a considerable time from dusk to midnight. I was able to do this for the first week, but in a fortnight I had to run all day and all night. In the districts in the South the conditions seem to be as different as can well be imagined. The system of charging for lamps on a fixed rate per lamp per annum robs the electricity supply of some of its principal advantages, such as staircase lights, switching on and off both ends. These lights only burn for about five minutes in the year, and I do not think they put up the cost to the electricity undertaking. I think a better way would be to charge a certain sum per annum, based on the rateable value of the house, and a very low price per unit—say, 12½ per cent. on the rateable value, and 1d. per unit. Mr. Handcock speaks about the water supply being something similar to the electricity supply, and suggests that electricity could be charged for in the same way. I do not think they are similar, for no one wants to run a tap down a sink, but people might leave their lights on to keep burglars away when they went out, and might keep passage lights burning unnecessarily. The author says that 60-c.p. lamps are too large for a private house, and he rather makes me blush, for I started off with a 16-c.p. in one particular room, then I had two 25-c.p., and ultimately four 25-c.p., and now the room does not look overlighted. I think it is a big mistake to assume that the consumer does not know

about electrical matters. I think in Lancashire he generally does know what a unit is, because people who work in the mills and workshops get a good idea from their general associations. With regard to cottage houses, a large number do not use 10s. worth of gas in a year, and I do not think they are, from a financial point of view, worth connecting up for electric light, because the cost of the service of the collection of accounts is so great; but one does not, of course, refuse any consumer, and they sometimes help other more profitable consumers to come on. There is no doubt about it that free wiring tends to bring on the consumer, but it also tends to bring on the bad consumer, and I consider it bad finance for the electricity undertaking to sink money in such work. There is the further trouble that when the tenant leaves the next tenant wants the light in a totally different place, and the wiring must be altered for nothing, or he will not use electric light at all. The arrangements shown for the connecting up of small consumers would come in very well if a whole row of houses could be wired at a time, but this is not easy in Lancashire towns. Mr. Stewart.

Mr. A. S. L. Barnes: I am in entire agreement with the views expressed by the authors on page 59 in the second paragraph, and page 62 in the first two paragraphs. As regards fixed charges for lights *versus* charging by meter, I think the authors put the case for the "contract" system much too mildly. We make far too much of the necessity of having meters installed. On the one hand there are the advantages of saving in capital costs of meters, in repairs, etc., and in salaries of staff, and to set against this there is the running costs of supplying some *additional* units on account of some people not being so careful as if they had meters. In the paper, on pages 62 and 73, it is assumed that the running cost of additional units is the same as that of the original units supplied, but this is very far from being the case, and for estimating purposes I should put the cost at not more than one-half, and more probably in the region of one-fifth or one-sixth. In the figures given on page 73, if it be assumed that the cost of additional units is only 0·22d. per unit instead of 0·44d. the "net increased profit" would be not £159 but £569. The running cost of additional units can be well ascertained by subtracting the average running cost per unit in the second and third quarters of the year from the average running cost in the first and fourth quarters. I think many central station engineers make a great deal too much of the loss of a few additional units. Our Chairman, when Mr. Yerbury read his paper on January 25th, this year, on "Equitable Charges for Tramway Supply," spoke very strongly on the subject of allocating the cost of coal partly as a fixed charge and partly as a running cost; I gathered at that meeting that many members did not realise what a large proportion of the total coal used in a station is necessary merely for being ready to supply. Some time ago I had an opportunity of ascertaining this cost in Gibraltar, as on several occasions for a whole day shift the supply was shut off though the steam pressure was kept up. The amount of coal used under these conditions, when worked out for Mr. Barnes

Mr. Barnes. the whole day, came to 25 per cent. of the total cost used in the day. I also tried to arrive at this by plotting a curve of coal used, and units generated on each shift, and by drawing the curve back to the zero line, a result very closely in agreement with the foregoing was obtained. Personally I would go even further than the Chairman in this matter, and say that the proportion of coal allocated as a fixed charge should be that used, assuming a proportion (say one-quarter) of the engine power required on the peak load to be running, but not actually supplying current, as one cannot be ready to supply until the engines are running, and there is a certain fixed amount of steam used, and therefore coal burnt, whether there is any load on the generators or not. This is one of the main reasons why additional units costs so much less, in running costs, than those constituting the original supply. A great advantage of supplying on what the authors call the "contract" system is that people like to know what they are going to pay, and many consumers will even pay a little more, as a fixed charge, rather than be troubled with varying amounts registered by meter, and with questions of meters running fast or slow. In Gibraltar, after the advent of metallic filament lamps, we began to charge a fixed rate per lamp, but on a reducing scale, somewhat on the lines of the charges referred to in the third paragraph on page 62 of the paper. The maximum number of lamps supplied on this system was 5, as it was only intended to apply it in small flats and shops. A large influx of new consumers resulted, and several old ones, who had meters, requested to be charged on this system, although in some instances it meant their paying more, but they were quite contented, as they knew exactly what they would be called upon to pay, without any question or dispute arising. We took the risk of these people using their lights unnecessarily, and although an inspector was sent out frequently to try and catch people doing so, no instance worth taking any notice of was ever reported. I would like to say that I am convinced of the truth of the statement in the sixth paragraph on page 67 that "an electric light company can deal with the consumer on this" (the fixed charge per lamp) "basis and make a profit out of it." It is very attractive to the consumer, and should be almost equally so to the suppliers.

Mr. Swinburne. Mr. T. H. M. Swinburne: I think the authors touch upon an important point when they refer to the question of the supply authority doing the wiring of premises directly or indirectly. There is no doubt that the wiring of a small consumer's premises is a great stumbling-block to him, and to lay out money in that way, together with the necessary staff to canvass the district and get the whole business thoroughly organised, is a much more sensible way of spending it than on expensive buildings. It would seem that supply authorities, both municipal and commercial, will sooner or later have to take such matters more completely into their hands. I would like to ask the authors whether they could give us any information regarding 10-c.p. 200-volt lamps, and whether this lamp is likely to be on the market soon.

Mr. Watson.

Mr. S. J. WATSON: The question of tariffs has probably been more discussed by supply engineers than any other problem with which they have to deal, and we appear to be as far as we were fifteen or twenty years ago from arriving at a solution which will deal in a satisfactory manner with all classes of consumers. I have no doubt whatever that the great diversity of practice which at present exists in the methods of charging for the supply does the industry harm. It is to be regretted that such a condition of affairs should continue, and I venture to express a hope that any further changes in tariffs may be in a direction which will eventually enable all supply undertakings to adopt the same principle, even although they may be unable to adopt the same scale. The question of charging for domestic houses appear to be the most pressing at the present time, largely owing to the advent of the metallic filament lamp, and to the growing demands for other electric domestic articles. As things stand at present, if a private house requires light and heat, it is a common practice to provide two separate sets of wiring and two separate meters, instead of one set of wires and one meter. A number of different methods of simplifying this arrangement have been discussed at different times, but the method now suggested by Mr. Handcock does not solve the difficulty, and as far as I know, the only system which makes it possible to deal with consumers of this class in a perfectly straightforward manner, is the method mentioned by Mr. Stewart; that is, charging people partly on their rateable value and partly by actual consumption. To take an illustration, the standing charge is usually from 10 to 15 per cent. on the rateable value, and 1d. or 1½d. per unit supplied. In the case of a private house rated at, say, £32 per year, and taking 12½ per cent. and 1d. per unit, the standing charge becomes £4 per year, and if they use 480 units, the total account will be £6 per year. I may say that I have recently been looking into the question of tariffs for private houses, and there is no doubt that under the majority of systems, including the method suggested by the authors, the tendency is to reduce the number of points wired or the number of lamps capable of being used. Supply undertakings, however, want the whole house wired both for lighting and other purposes, and this is much more likely to be done if a consumer knows that after paying a certain standing charge, he will only pay, say, 1d. for every unit used. The authors say that as regards metallic filament lamps, the action of these on the income of supply undertakings will probably be intensified in the future. I believe, however, that we have almost, if not quite, passed through the stage where the metallic filament lamp will have a detrimental effect on the income. It is quite true that owing to the adoption of these lamps the revenue from lighting supplies has remained stationary, or even receded in some cases, but in the majority of towns the units sold for lighting are again gradually on the increase. As a rule, the first lamps to be changed from carbon to metallic filaments are those used the longest, and it is not of any great consequence to the supply undertaking whether the short-hour lamps have carbon or metal filaments, as the

Mr. Watson.

annual consumption in either case is so small. On page 62 the question of supplying unremunerative short-hour consumers is mentioned. Of course, none of us are keen to obtain such consumers, but at the same time it seems to me that the tariff should be so framed as to encourage all classes of the public to use the supply, and deliberately to keep certain classes off your mains is not, I think, a very desirable thing. Referring to the reduced cost of wiring and to the "free" wiring of houses, I have always held the opinion that it is no part of the duty of supply undertakings to carry out installation work, and particularly to instal "free" wiring. I know of many cases where considerable sums have been spent on the so-called "free wiring" systems with very lamentable results to those who have found the money for that purpose. Changes of tenancy and ownership occur, and if the installation goes out of use it is impossible to recover any appreciable part of the outlay, and consequently the rate of depreciation must be very high. With regard to the question of "dusk-to-dawn" supply, I cannot agree with the authors' suggestion. One of the principal things that all supply undertakings at the present time are trying to get the public to take up are small domestic articles, such as electric irons, heaters, etc. To build up a business with articles of that character, it is absolutely necessary to give a twenty-four hours' supply, and there is no doubt that in time an appreciable load will be built up out of these small things, so that a supply for a limited number of hours per day is not likely to be very successful.

Mr. Handcock.

Mr. HANDCOCK (*in reply*): There is no doubt that within the last two years the standard of illumination has increased very materially, and where previously a consumer was satisfied with a 16-c.p. lamp, he may now consider 25 c.p., or even 50 c.p., none too much. One speaker referred to the question of running along the front of buildings. There is no doubt that where this can be done the advantage in the matter of the cost of services is great, and I may mention that to my knowledge there is one company which has statutory powers which enables it to run wires along the fronts of any buildings within its area. The question has been raised as to the relative costs of the renewals of gas mantles, etc., as compared with that of metallic filament lamps. It will be found on going into the matter carefully that for public lighting, at least, the annual cost of renewal of gas mantles, chimneys, and incidentals, works out at practically the same as that of metallic filament lamps at current prices. It is somewhat difficult to answer the question as to the annual rental, which may be taken as the dividing line between premises to be charged on the contract basis and the premises to be charged on the flat rate or other similar systems. Districts vary very much in this respect, and the habits and spending powers of a consumer in one district occupying a £50 a year house, for instance, may be entirely different from those of another consumer occupying a house of a similar value in another district. It is dangerous to generalise or to draw analogies between different districts; each district has its own characteristics, which

must be carefully studied on their merits. At present, in some places, the amount that a gas consumer with twelve lights, for instance, spends per annum may be as much as £1 per light, and yet, owing to contingent circumstances, gas is in undisturbed possession of the field. It is possible that in some cases the limit indicator will be preferred to installing special lamp-holders. This offers considerable advantages, as one does not then have to control in any way the lamps used by the consumer; all that has to be done is simply to set the limiter for the maximum wattage of lamps installed at the time that he is connected. This causes no inconvenience to the consumer either, as the limiter only acts in the event of his surreptitiously increasing the candle-power of his lamps. One speaker referred to the use of transformers. In the matter of small transformers there has been a wonderful improvement since a demand for them in some quantity has arisen, and those who have not gone into the question will be astonished at the high efficiencies that it is possible to obtain in small transformers to-day, and the very small price at which it is possible to purchase them. In days gone by magnetisation losses were a very big item, but this need no longer be the case. The "dusk-to-dawn" system of supply is one that can in no sense be regarded as a permanent arrangement for any station; it is, nevertheless, very convenient for getting stations on to their feet in small lighting districts; by putting it into force in many cases the station is at a comparatively early date brought up to the stage when a twenty-four hours' supply will be both justified and advantageous. Certain speakers have referred to the fact that the amount which they are paying per lamp per annum on the flat rate would not justify their taking current on the contract system. These speakers bring out exactly the point we wish to emphasise—that is to say, they are not gas consumers, and they do not occupy such small premises that the cost of illumination in proportion to the number of lights installed is large. The contract system, as one speaker reminded us, is by no means new, and it has been extensively in use in various countries. It was not, however, suitable to this country, having regard to the circumstances that pertained in the days of carbon filament lamps. It is the advent of the metallic filament lamp that has caused us to reconsider the position. The ideal method of charging has yet to be found, and with the Chairman, both my colleague and I think that in certain cases the method of charging on the basis of the rateable value may be found extremely convenient. It is a great pity that one finds a different method of charging in nearly every district, and it is very much to be desired that a tariff may be found which will be sufficiently elastic to become universal.

Mr. Handcock.

SOME NOTES ON OVERHEAD LINE CONSTRUCTION.

By W. B. WOODHOUSE, Associate Member.

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INTRODUCTORY.

It is proposed in this paper to deal with the construction of what are usually described as "transmission" lines; that is to say, high-pressure overhead mains run across country on private property crossing roads and railways and avoiding buildings, villages, and towns as far as possible.

The design of low-pressure overhead mains run along highways and through towns although possessing many points of interest is so much controlled by local conditions that a general discussion is of little value. It may be noted, however, that the use of such mains is the only commercial solution to the problem of distribution in small towns and sparsely populated districts.

The cost of a transmission system is a matter of much greater importance than is usually realised, it is a matter of public importance. Where a cheap power supply exists the prosperity of the district is stimulated, existing industries extend and new ones arise, transport facilities are improved, and the spread of population into rural districts encouraged.

The abolition of smoke in manufacturing districts is a matter that concerns the health of every inhabitant, and the use of electric power offers the only satisfactory solution. If by the use of overhead lines a power supply may be cheapened or may be introduced into a district where it would otherwise be impossible, then every reasonable facility should be given to the supply authority to carry out the necessary work.

LEGAL RESTRICTIONS.

The use of such lines in this country is subject to conditions so onerous as compared to those of other countries that small progress has been made, and it would be no matter for surprise were their use less general than is the case. Amendment of the present restrictions is most needed on three main points:—

1. Modification of the veto possessed by local authorities.
2. Compulsory wayleaves.
3. Less stringent Board of Trade regulations.

The Electric Lighting Act, 1882, imposed the restriction on undertakers that no overhead line should be erected without the consent of the local authority, even though wholly on private property. This veto was granted in the days when it was seriously proposed to light our large towns by the aid of overhead wires, power supply and long-distance transmission being then unknown.

The protection granted to the local authority, necessary as it may be in some cases, is open to abuse in many others. Local authorities are not aptly constituted to decide whether a projected line is in the public interest, and local feeling may decide such a matter on narrow lines.

The veto should be reduced to a reasonable one instead of being absolute, and the final decision should be in the power of the Board of Trade. It is of almost equal importance that the decision should be made in a reasonable time. The procedure governing the laying of underground mains might well form a model.

As signs of a movement in the right direction, several power Acts reduce the local authority's veto to a reasonable form, powers have been granted to undertakers for fixing rosettes on buildings to support lighting and tramway wires, and the compulsory use of tramway poles for Post Office telegraph wires may be noted ; but this piecemeal legislation cannot be considered a satisfactory way of dealing with a matter which affects the country at large.

Compulsory wayleaves for overhead lines are sadly needed. An unreasonable landowner or tenant may, by his action, prevent the construction of a whole line, or may put the undertakers to very considerable expense to avoid his land. In other more favoured countries legal machinery exists for fixing the most reasonable route, deciding on the wayleave payment, and ensuring that the settlement is not unduly delayed. Norway, France, Switzerland, and Italy may be mentioned as examples.

The present regulations of the Board of Trade require factors of safety to be observed which, as compared to those used by designers in other countries, are very high, and they add considerably to the cost of construction. It is hoped that time will see amendment on several of the existing restrictions.

The Effect of Local Conditions on Design.

For transmission distances likely to be required in this country electrical conditions are simple, and the designer is only concerned with them so far as they affect the weight of the conductor.

The physical surroundings of a projected line have an important bearing on its design, and may often decide the general type of construction. In the majority of cases the line will traverse pasture or arable land, more rarely moorland or marsh, and it will therefore be intersected by hedges, walls, and fences of an amazingly unnecessary number, and of random direction. These boundaries form convenient

sites for the poles, as involving the least disturbance to the land tenant, and if wayleave payments are to be kept within reasonable bounds, spans must be varied, angles avoided, and single poles used in preference to A or H poles.

CONDUCTORS.

The nature of the conductors must first be decided; practically but two metals are available—copper and aluminium. A comparison of the relative costs of these on the basis of resistance is obviously not sufficient to decide the choice; the strength and cost of the supports must also be regarded. Copper has for many years been used for overhead conductors, but a satisfactory specification for hard-drawn copper wires has not yet been generally agreed upon.

The sizes of single wires most likely to be required are from No. 7 to No. 4/0 gauge; between these limits solid conductors are of a size to be easily handled, and possess advantages over stranded cables. For larger areas stranded cables are advisable owing to their greater strength and flexibility. So far as single wires go we need, therefore, only consider two ranges of, say, Nos. 18 to 15, and Nos. 7 to 4/0 inclusive, and the specification of such wires should indicate (1) the breaking stress, (2) the ratio of the stress at the elastic limit to the breaking stress, (3) the ratio of stress to strain within the elastic limit (4) the behaviour of the metal under torsion and under repeated bending.

The breaking stress in pounds may be expressed as $F = A - B\delta$, where A and B are constants, and δ is the diameter of the wire.

From tests published by Mr. Bolton* $A = 79{,}000$, $B = 41{,}800$ for wires between No. 7 and No. 4/0. These figures are rather high, and it may be taken in round numbers that $A = 70{,}000$, $B = 40{,}000$ are safe values. The safe stress (Board of Trade Rules) is one-fifth of this, or—

$$F = 14{,}000 - 8{,}000\,\delta.$$

It is of advantage, of course, that this figure should be high, but it is also important that the wire should be fairly elastic, and a very high ultimate strength is not consistent with the latter requirement.

The determination of the elasticity of a wire by tests on a 10-in. specimen is of doubtful value, and all tests should be made on lengths approaching the span lengths to be used.

The writer's method of doing this is sufficiently accurate for practical purposes, and does not require the use of a testing machine (Appendix I.).

The ratio of the elastic limit to the ultimate stress is of interest, but with a factor of safety of 5 the designer need not consider it, as in wires such as would be used it is of the order of from 50 to 70 per cent.

* *Electrical Review*, vol. 60, p. 131, 1907.

The torsion and bending tests are valuable as a guide to the behaviour of the wire in use, kinking during erection and afterwards ageing due to constant swaying being the most likely causes of failure.

Aluminium has been used for a number of important lines in America, and deserves consideration. So long, however, as the present factors of safety are required by the Board of Trade, aluminium is not likely to be extensively used here.

The principal properties of hard-drawn copper and aluminium are compared in Table I. for wires of No. 6 gauge.

TABLE I.

Comparison of Aluminium and Copper Wires.

	Aluminium.	Copper.
Weight per cubic inch, lbs.... ...	0·0967	0·322
Ultimate stress, lbs. per square inch	26,000	62,000
Elastic limit, ratio, per cent. ...	54	70
Elongation with a stress of one-fifth ultimate, per cent.	1	0·4
Linear expansion for a rise of 53° F., per cent.	0·069	0·05
Relative conductivity...	62	100

Stranded aluminium cables are used in preference to solid wires owing to the increased tensile strength, the lessened risk of damage from scratches and kinks, and the greater flexibility. In making comparisons between the two metals this must be borne in mind, as although stranding gives these advantages, yet the diameter of the cable for a given cross-section is greater than that of a solid wire, and the cable presents a greater surface to the wind.

The ratio of the diameter of an aluminium cable to that of a solid copper wire of equal resistance per unit length is (for sizes of copper wire from No. 8 to 4/0) 1·44 : 1.

WIND PRESSURE ON WIRES.

A suspended wire is loaded in two ways: (1) By its weight vertically, (2) by wind pressure on its surface, assumed, horizontally.

The maximum tension on a wire suspended between rigid supports will occur at minimum temperature and maximum wind pressure. The Board of Trade Rules require that the maximum tensile stress calcu-

lated for a temperature of 22° F., and a wind pressure of 30 lbs. per square foot, shall not exceed one-fifth of the breaking stress.

The tension due to weight alone is, approximately, $\frac{w\,l^2}{8\,s}$. The tension due to a wind pressure of the above amount is $\frac{l^2}{8\,s}\left(\frac{\delta}{8}\right)$. The tension due to the resultant is, for solid or stranded conductors—

$$T = \frac{l^2}{8\,s}\sqrt{w^2 + \left(\frac{\delta}{8}\right)^2}.$$

It is obvious, as the strength is proportional to δ^2 and the wind loading to δ, that the smaller wires are proportionately more heavily loaded. The tension which may be applied to a wire in still weather will therefore vary with its diameter, but the variation will be to some extent compensated for by the greater ultimate strength of the smaller wires.

As the wires will not be strung under the conditions of weather stated above, it is necessary to know the corresponding tension and sag during still weather at some higher temperature, and also, a figure of importance, the maximum sag corresponding to summer weather.

The following method of obtaining these figures is a fairly satisfactory one; it is given step by step for clearness, but in actual use may be shortened by combining certain of the calculations.

Determination of Sag at any Temperature, Allowing for Wind Pressure and Elasticity.

Given the following data:—

Span (l), diameter of wire (δ), weight of wire per cubic inch (ρ), elastic strain for a given stress, coefficient of linear expansion per °F, safe stress of wire (F_m).

The procedure is:—

1. Calculate the sag corresponding to the maximum allowable stress due to wind pressure and weight—

$$s = \frac{l^2}{8\,a\,F_m}\cdot w\sqrt{1 + \left(\frac{\delta}{8\,w}\right)^2}.$$

2. Calculate the component of the maximum stress due to weight only:—

$$F_0 = \frac{l^2}{8\,a\,s}\cdot w = F_m \times \frac{1}{\sqrt{1 + \left(\frac{\delta}{8\,w}\right)^2}}.$$

3. Calculate the length of wire for the given span (l), and the sag above determined—

$$L = l + \frac{8\,s^2}{3\,l}.$$

4. From (3) calculate various corresponding values o $(L - l)$ and F, taking as one pair of values F_0 and $(L - l)$ from equation (3)—

$$F^2 = \frac{l^3 \rho^2}{24} \times \frac{1}{L - l}.$$

5. Plot the curve connecting $(L - l)$ and F (Fig. 1), and mark the point (P) having as abscissa the value of $(L - l)$ corresponding to sag s in equation (3), and ordinate the value of F_0. Mark also on the same ordinate the value of F_m (Q).
6. From the known properties of the wire calculate the elastic contraction due to a reduction of stress from F_m to F_0, and set off P N, negatively, equal to this. Join Q N cutting the

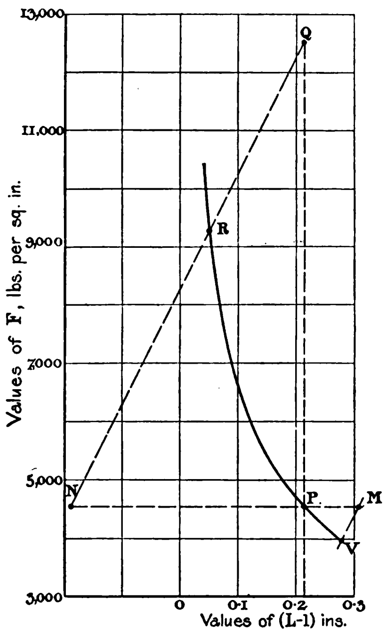

FIG. 1.

curve at R. The ordinate to R will equal the stress on the wire at minimum temperature with the wind load removed, and the corresponding sag may be calculated—

7. From N set off, positively, N M equal to the elongation due to a rise of temperature from 22° to 75° F. Draw M V parallel to Q N cutting the curve at V. The ordinate to V equals the stress at summer temperature in still weather, and the

maximum sag may be calculated therefrom. To find the stress at any other temperature N M is reduced proportionately.

The stress for any other span with a wire of the same size may be deduced from the curve by proportion; *e.g.*, if the span be changed from l_1 to l_2, the value of $(L - l)$ for the same stress is increased as $\left(\frac{l_2}{l_1}\right)^3$, the elastic strain is increased as $\left(\frac{l_2}{l_1}\right)$, and the temperature strain in the same ratio.

The effect of using a wire of a different degree of elasticity may be studied by means of the curve.

As an example, calculations have been made for a No. 6 copper wire and a span length of 1,000 in.

$$F_m = 14{,}000 - 8{,}000\,\delta = 12{,}500 \text{ lbs. per square inch.}$$

$$F_0 = \frac{F_m}{\sqrt{1 + \left(\frac{\delta}{8w}\right)^2}} = 4{,}520 \text{ lbs.} \quad \text{,,} \quad \text{,,}$$

$$\text{The sag corresponding to } F_0 \ldots = \frac{\rho\, l^2}{8\, F_0} = 8{\cdot}91 \text{ in.}$$

$$\text{The value of } (L - l) \text{ for this sag} = \frac{8\, s^2}{3\, l} = 0{\cdot}211 \text{ in.}$$

and $L = 1{,}000{\cdot}211$.

A wire of this length loaded only by its own weight will have a tension of 4,520 lbs. per square inch, and a sag of 8·91 in.; for other values of L the tension will vary accordingly, and the curve in Fig. 1 is plotted therefrom.

Mark at P, $F_0 = 4{,}520$; at Q, $F_m = 12{,}500$. The change of stress $F_m - F_0 = 8{,}000$ approximately, and the elastic strain being given as 0·05 per cent., for a stress of 10,000 lbs. the actual elongation due to this change of stress is 0·4 in.

Set off P N = 0·4. Join Q N, the intersection gives R, whose ordinate is the value of the winter stress in still weather (= 9,300 lbs. per square inch). Set off N M equal to the elongation due to temperature rise $= \frac{1}{2000}$ for 53° F. Draw M V. The ordinate to V is the summer stress in still weather (= 3,950), and the corresponding sag is 10·2 in.

In the same way the sag may be determined for other spans, *e.g.*, for a span of 2,000 in., the values are—

		F.	Sag.
Conditions of maximum stress	...	12,500	35·6
Conditions of minimum stress	...	4,300	37·4

The further work of design may be much simplified by constructing a set of curves embodying the above calculations, and certain calculations as to the strength of supports which are dealt with below.

Poles.

Poles used to support wires are subject to three loadings under normal conditions ; the weight of the wires, the wind pressure on the wires as sustained at the points of support, the wind pressure on the pole-surface and its top hamper (brackets, arms, insulators, etc.). At angles the component of the wire tensions must be added and either met by a stiffer pole or by staying. Leaving abnormal conditions, such as the effect of broken wires, to be dealt with later the important stresses are seen to be due to wind pressure on poles and wires.

For spans up to 100 yards wooden poles are cheaper than iron, for longer spans lattice-work iron towers may show an advantage in cost.

Wooden poles are usually of red fir, winter felled, and creosoted. The poles should be well seasoned before creosoting, and if properly treated will have a life of 15 to 20 years under average conditions.

The taper of the poles is a matter beyond our control, but it is advisable to use only poles having a maximum strength of rupture at the ground section, as in course of time this part of the pole will decay most rapidly. Assuming the load concentrated at the pole-top, the proportion of taper to secure this is that the diameter at the top should be not less than two-thirds of the diameter at the ground. The depth to which it is necessary to set the poles in the ground depends, of course, on the nature of the soil—usual practice is to allow from 5 to 8 ft.

The breaking load of a fir-pole is expressed by $W = 766\frac{D^3}{H}$, a formula derived from the Post Office tests. As under the Board of Trade rules a factor of safety of 10 must be allowed, the safe load is one-tenth of the value found from the above.

To the designer the important figure is not the above value, but is the net strength available for resisting the wind load on the wires, which is found by deducting from the safe load, the load due to wind pressure on the pole-surface, insulators, brackets, etc.

If H be the distance from the ground to the point of loading, the surface of the pole above this plus the insulator and bracket surfaces may be reduced to an equivalent length of pole-surface.

The gross safe load applied at a distance H from the ground, neglecting wind pressure on pole, is—

$$W = 76{\cdot}6\,\frac{D^3}{H}.$$

The net safe load, equivalent to wind load on wires, is—

$$\frac{1}{10}\,\frac{D}{H}\left(766\,D^2 - \frac{H}{16}(H + A)\right)$$

where A is the equivalent extra length of pole-surface.

As an example of the magnitude of this allowance the maximum safe load on an 8-in. pole at 30 ft. with $A = 3$ ft. is reduced below the gross by 18 per cent. In specifying a series of poles of varying

heights for general purposes the net strength is the figure of importance. From the formula above given a series of poles of equal net strength may be calculated.

We may now proceed to draw the working curves. It is convenient to plot in the quadrants between the rectangular axes:—

1. Span and stress in wires.
2. Span and wind load on wires.
3. Net pole-strength and height to loading-point for poles of various diameters.
4. Stress in wires and summer sag.

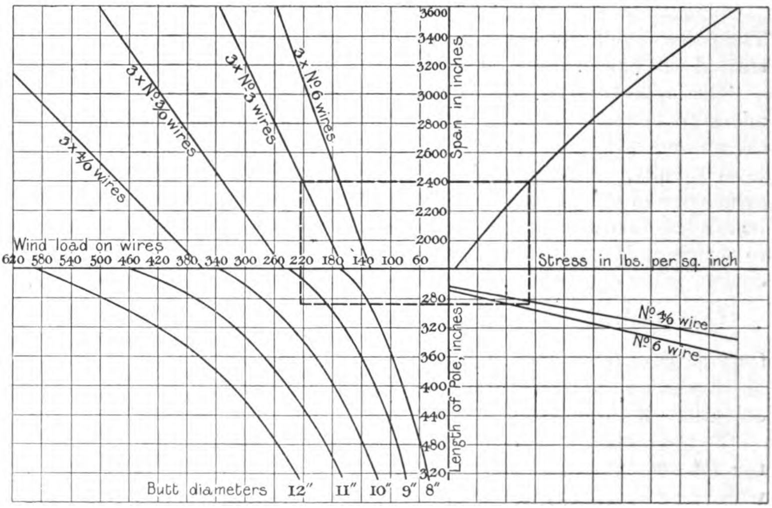

FIG. 2.

From these curves the effect of varying the span on the size of poles can be readily seen and the merits of each particular case considered.

Example.—If three No. 3 wires are to be used the span is assumed at any likely figure, say 200 ft. (it may be fixed by physical conditions). Reference to the second quadrant and the line corresponding to three wires of No. 3 gives the wind load on wires which is equal to the net pole-strength required. The minimum head room being 20 ft., reference from the first to the fourth quadrant gives the maximum summer sag and therefore the length of pole required (20 + summer sag) = height to point of loading (24 ft.). Following the abscissa from this point into the third quadrant to its intersection with the ordinate representing the net strength required gives, if the point falls on a "diameter" curve, the size required (namely,

diameter = 9·5 in.); if it falls between curves the next larger diameter must be chosen.

It may be noted that the heights corresponding to the intersection of an ordinate in the third quadrant with the "diameter" curves will give the scantlings of a series of poles of varying height and equal net strength.

Flexible Supports.

The previous consideration has dealt only with normal stresses. Of abnormal stresses the breaking of all wires in one span, and the consequent loading of the support by the unbalanced tension in the remaining spans is the most important. It is obvious that a support

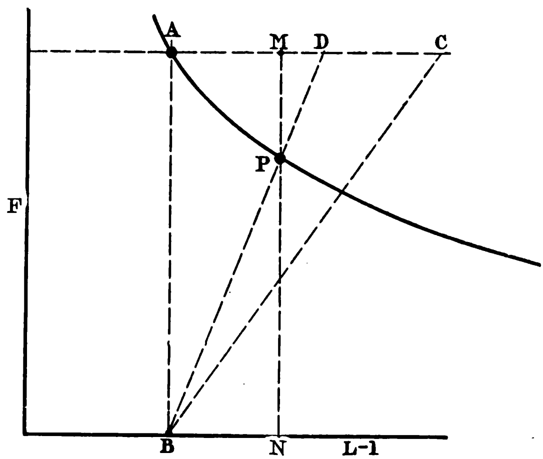

Fig. 3.

which is elastic in the direction of the wires will in such a case reduce the tension.

The advantages of flexible poles in line construction have been pointed out by Mr. A. P. Trotter, and a method of analysing the above case given.* In addition to the flexibility of the poles there are many modifying circumstances tending to prevent the wrecking of a number of spans due to such a cause as the above. Wire clips to the insulators will break and allow the wire to slip, insulator pins and arms will bend and foundations will give. Small deviations on the points of support from the straight line are a natural advantage which it is difficult to avoid. Vertical deviation of the supporting points may be taken advantage of to equalise stress under varying conditions if flexible suspensions are used.

The effect of an elastic pole in modifying stress due to broken wires

* *Proceedings of the Institution of Civil Engineers*, vol. 169, p. 183, 1907.

may be studied by means of a diagram connecting $(L - l)$ and F. The unbalanced load on the pole will cause a deflection within the limits of elasticity until the tension of the wires equals the elastic force. For wooden poles the deflection as ascertained by Post Office tests is—

$$\text{Deflection} = \frac{1}{216{,}000} \times \frac{W H^3}{D^4}.$$

For a single span the determination is simple (Fig. 3).

Let the ordinate to A represent the stress in one wire and assume all n wires break. The pole deflection with stress is known. Set off from B a line B C so that A C = pole deflection corresponding to $(n \times F)$. Set off from C, C D equal to the elongation of wire at stress F. Join B D, then P gives ultimate deflection of pole and stress per wire corresponding to equilibrium. This assumes the second pole from the break to be rigid, if it be not so it will deflect away from the break due to the initial difference of stress represented by n (A B — P N). The case has been analysed by Mr. Trotter, who states that the effect will not be appreciable past the fifth pole.

The effect of a deviation of the supports from a straight line in equalising the stress on the wire at all temperatures is of interest.

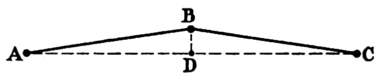

FIG. 4.

Let A B C be three supports, the deviation of B from the straight line being B D. There is due to the tension of the wires a tendency for A and C to bend approximately at right angles to A C, and for B to bend in the opposite sense. Assuming the wires to contract due to a fall of temperature, this bending movement becomes greater, and the poles will deflect so as to decrease the stress on the wires.

Let $AD = l$, $DB = x$, $AB - AD = e$, $\angle BAD = \theta$. Then, approximately—

$$\frac{BD}{AB} = \frac{x}{l} = \theta,$$

and—

$$\frac{e}{x} = \theta = \frac{x}{l},$$

$$\therefore \; x^2 = e\,l.$$

Let $l = 2{,}000$ in., $x = 10$ in., then $e = 0{\cdot}05$ in., equivalent to a decrease of the span by this amount.

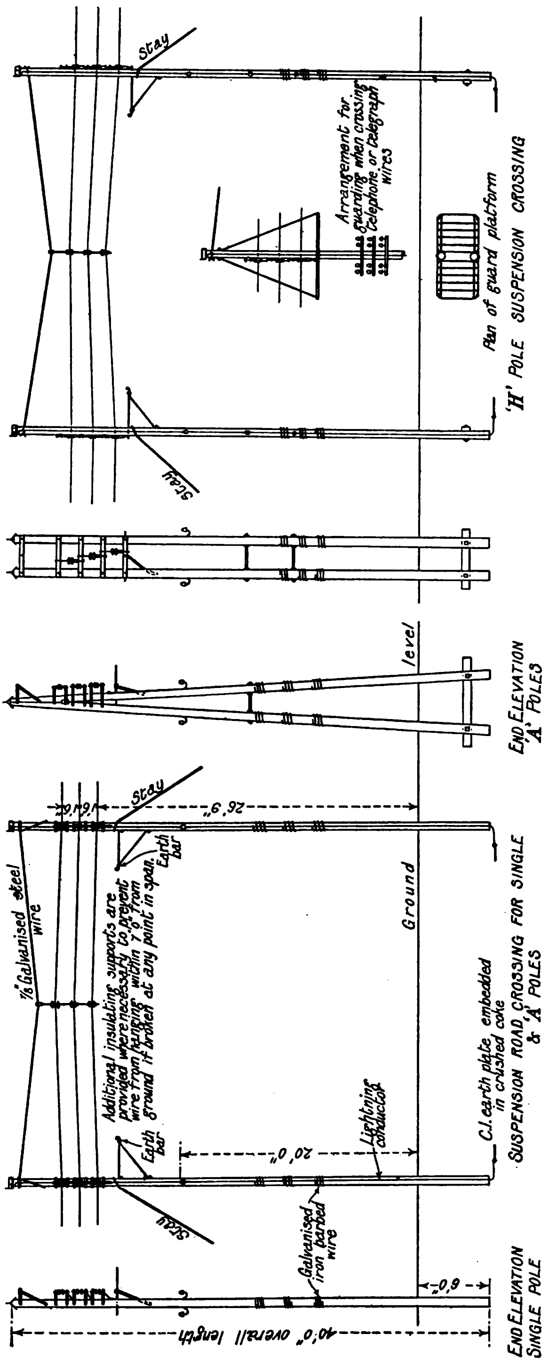
Stay
Arrangement for guarding when crossing telephone or telegraph wires
Plan of guard platform
'H' POLE SUSPENSION CROSSING
Stay
level
END ELEVATION 'A' POLES
26' 9"
1'6" 1'6"
Stay
Earth bar
⅜" Galvanised steel wire
Additional insulating supports are provided where necessary to prevent wire from hanging within 7' 0" from ground if broken at any point in span.
Ground
C.I. earth plate embedded in crushed coke
SUSPENSION ROAD CROSSING FOR SINGLE & 'A' POLES
Earth bar
20' 0"
Lightning conductor
Stay
Galvanised iron barbed wire
6' 0"
40' 0" overall length
END ELEVATION SINGLE POLE

FIG. 5.

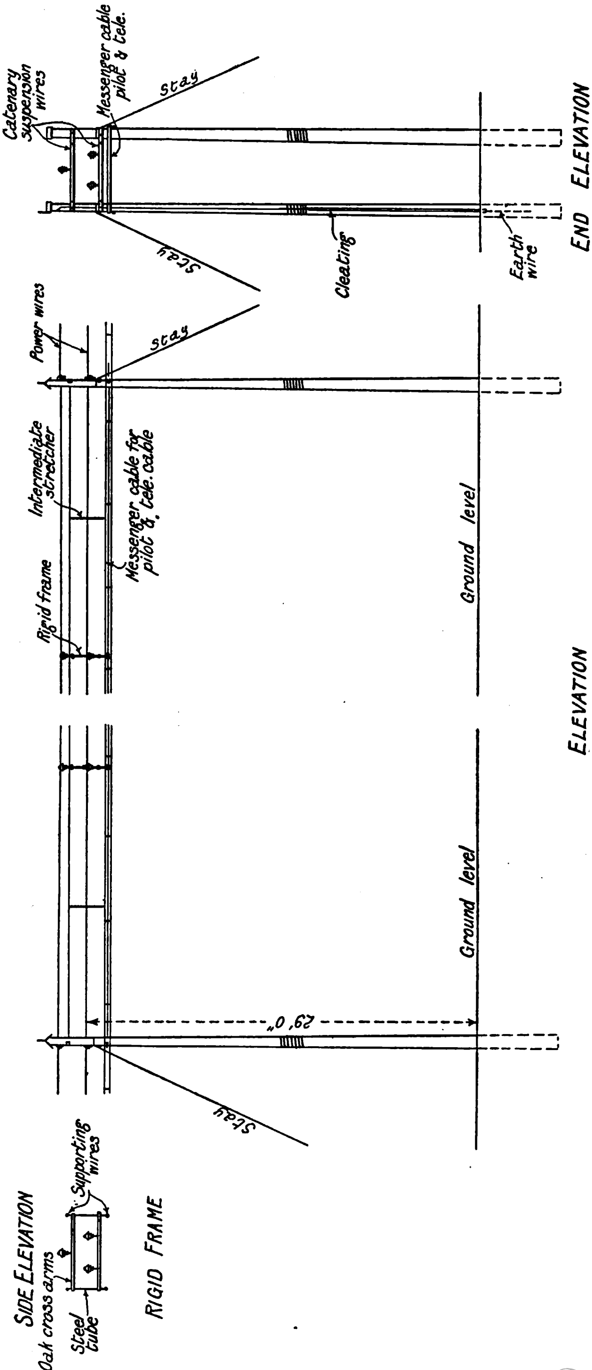
Catenary suspension wires
Messenger cable pilot & tele.
Stay
Stay
Cleating
Earth wire
END ELEVATION
Power wires
Stay
Intermediate stretcher
Messenger cable for pilot & tele. cable
Rigid frame
Ground level
ELEVATION
Ground level
29' 0"
Stay
SIDE ELEVATION
Oak cross arms
Steel tube
Supporting wires
RIGID FRAME

FIG. 6.

Special Work.

It will be seen from the above discussion that the design of a straight line resolves itself into a simple matter as regards the wires and poles.

The special work required at angles, road, and railway crossings, will, however, considerably add to the designer's duties. In such cases as road-crossings safety and security are of paramount importance, and there are many types of cradles and supports in use ; the type of road-crossing adopted by the writer is a catenary suspension (Fig. 5) ; cradles are unsatisfactory and unsightly, and this suspension appears to possess advantages.

The type of railway crossing approved by one of the principal railway companies is given as an example of sound but simple construction (Fig. 6).

Terminal arrangements for voltages up to 10,000 may be quite simple ; there is no need for the elaboration seen in designs for higher

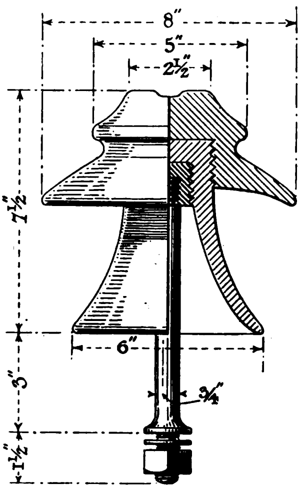

Fig. 7.

pressures. Of the other details of line construction but brief mention need be made.

Insulators.

The use of porcelain for insulators is general ; glass used in early high-pressure lines has been generally discarded for mechanical reasons.

The design of special insulators is rarely necessary on account of the number and excellence of the standard designs which may be bought. Should it be found necessary to design special insulators there is an important rule to be observed that the thickness of the clay should be kept as even as possible.

Large insulators are built up in sections cemented together. Fig. 7 shows the type adopted by the Yorkshire Electric Power Company for 10,000 volts.

Brackets and Arms.

The choice between a bracket and a cross-arm depends on the spacing and relative position of the wires. A symmetrical spacing is, of course, the best, but for moderate distances this is not of so much importance as the distance between wires; the minimum distance is determined by the possibility of short circuits due to birds or the swaying of the wires. Some tests made by the writer to determine the amount of the latter showed that a No. 4/0 wire spanning 50 yards with a 3 ft. 6 in. sag swung 3·5 in. each way during a severe gale; a No. 8 wire of the same span and a sag of 1 ft. 10 in. swung 3 in. each way. Birds are more likely to cause trouble at the poles than between wires.

Economical Span.

The total cost of an overhead line may be divided into four parts:—

Cost of wires.
„ supports.
„ labour.
„ wayleaves capitalised.

The cost of wires per mile is decided entirely by electrical considerations and with a portion of the labour costs is independent of the number of supports. The cost of supports per mile varies with the number, some items being increased in cost with an increased span and some decreasing.

If the number of supports per mile is decreased the poles must be stronger to meet the extra weight and wind load, they must be longer to maintain the same head-room against the increased sag of the wires, and the foundations must be made more secure. The brackets, arms, insulators, stays, etc., must be stronger and the labour of erection per pole is increased. Against these increases per pole, however, we must set the decreased number of supports, and therefore for any particular line there is a most economical span to be found.

It is not possible to generalise as the cost of the items varies considerably for different electrical requirements. It may be noted, however, that the strength of the poles, allowing for increased height with increased span, is approximately proportional to the fourth power of the butt diameter (D^4), and that the cost of wooden poles of lengths between 30 and 60 ft. is proportional to D^3.

The ratio of cost of poles per mile of line under these conditions is therefore—

$$\frac{\text{Cost with span } s}{\text{Cost with span } s_1} = \frac{\sqrt[4]{s_1 s^3}}{s},$$

which is to say that if the span is doubled the cost of poles will be increased in the ratio of $2^{\frac{3}{4}}$ (or 1·67) to 1.

The number of poles being decreased the total labour cost is decreased also; but, as each foundation will prove more costly, not to the same extent.

The decrease in the number of poles will also decrease the wayleaves, and taking all the items into consideration a balance may be struck. In practice one finds that over a considerable range of span variation the cost is fairly constant and the actual span length is decided by local conditions such as the position of hedges, boundaries, roads, etc. Using single poles under the present Board of Trade rules a span exceeding 100 yards is not economical. The limiting conditions may be found in the same way for any other type of support A poles, H, or steel towers.

APPENDIX I.

Testing the Elasticity of Wires.

Two wires of the size and material under observation are stretched between three supporting points in a straight line, spaced so as to form two equal spans. The wires are adjusted to have equal sags as measured as points midway between supports, and are then firmly fixed at one end and clamped together at the other, the clamp being connected to an adjusting screw by means of which the sag of the wires may be adjusted to any convenient amount. One wire is then lifted from the intermediate support and allowed to hang freely. If the supports have moved due to the change of tension the sag of the other wire will be altered. Adjust, if necessary, the sag of this wire to its original value and measure the sag of the wire having the long span. Then from the observed sags the stress corresponding may be calculated and also the elongation due to the difference of stress.

The calculation is as follows:—

Let—

f = stress corresponding to sag s.
f_1 = stress corresponding to sag s_1

Then—

$$f = \frac{\rho\, l^2}{8\, s}, \quad \text{and } f_1 = \frac{\rho\,(2\, l)^2}{8\, s_1}$$

$$f_1 - f = \frac{\rho\, l^2}{8}\left(\frac{4}{s_1} - \frac{1}{s}\right).$$

Let—

L = length of wire on span l.
e = elastic elongation of length L, due to an increase of stress, in inches.

Then—

$$L - l = \frac{8\, s^2}{3\, l} \quad \text{and } 2\,(L - l) + 2\, e = \frac{8\, s_1^2}{3(2\, l)}$$

$$\therefore\; e = \frac{2\, s_1^2 - 8\, s^2}{3\, l} = \frac{2}{3\, l}\left(s_1^2 - 4\, s^2\right).$$

Note that if the wire were inelastic e would be zero and $s_1 = 2\, s$, and therefore the stress on the double span also doubled. As an example the results of a test on a No. 6 wire are given below:—

TEST OF ELASTICITY OF NO. 6 H.D. COPPER WIRE.

Ultimate Strength, 61,000 lbs. per Square Inch. Span, 1,320 in.

Initial Sag, s	Final Sag, s_1	Difference of Stress.	Elongation per Single Span.
Inches.	Inches.	Lbs. per Square Inch.	Inches.
5	18·0	1,558	0·110
9	26·0	2,780	0·177
12	31·5	3,050	0·210
17	40·0	2,887	0·184

The average elongation for a stress of 40,000 lbs. per square inch from the above is 0·2 per cent.

APPENDIX II.

NOTATION USED.

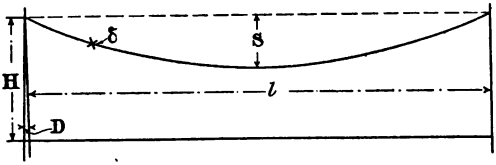

FIG. 8.

H = height of pole from ground to mean height of wires.
D = diameter of pole at ground.
l = length of span.
s = sag.
L = length of wire for a span of l.
δ = diameter of wire.
n = No. of wires.
a = cross-sectional area of wire.
ρ = specific gravity of material of wire.
F = stress in lbs. per square inch.
W = weight in lbs.

(All lengths are in inches.)

DISCUSSION.

Mr. W. EMMOTT: We find that local and geographical conditions settle the positions and nature of the supports to such an extent that a line cannot be laid out by formula, and the only thing to do is to make the factor of safety as large as possible. The author's remarks on suspensions are worth careful consideration by any one who has any overhead line construction work in hand. Mr. Emmott.

Mr. W. HARTNELL: The paper does not lend itself to much discussion, but it may be divided into two parts, viz., on the best path for overhead wires, and on the best method of supporting them. Regarding the calculations, we may take them as practically correct, and I am much pleased with their simplicity. The approximate formula for stress on the wire, with a flattish curve, is equally true whether the curve be considered as part of a parabola or part of a circle, or whether the centre of the wire be treated as the lower part of a girder equally loaded, having the same depth as the dip of the wire. I much admire the quadratic diagram in Fig. 2, which embodies a large amount of information. The very simple method on page 806 for calculating the combined stresses due to wind and gravity is a novel one. In power transmission we are placed at a great disadvantage in not having the facilities and encouragements that are enjoyed by other countries. Mr. Hartnell.

Professor Parr.

Professor G. D. A. PARR: I would like to ask the author whether he has tried glass insulators, which are extensively used in the States. I was under the impression that the difficulty with glass insulators had been got over in America by means of a non-alkaline glaze, the leakage being so much reduced thereby that the insulators could be used not only for high pressures but also in damp atmospheres, while owing to a special annealing process the glass did not crack or fly. With regard to the shape of the insulator shown in the paper, which I understand has been adopted by the Yorkshire Power Company, I certainly think it would have to be of porcelain effectively to stand the climate of this country. The outer shed appears quite useless. It is true that the leakage takes place over a large surface, but if the correct shape of the insulator be as shown it is possible for the water to beat completely round the outside of the inner shed, as well as under the lip and on the outside of the outer shed, so that practically only the interior of the inner shed is effective. If the special glass insulator were fitted with sheds more effectively shaped than that shown in the paper they might perhaps be found satisfactory. I should like to know whether the author has found them to fail.

Mr. Wright.

Mr. H. H. WRIGHT: The author mentions early in the paper that there are great difficulties in obtaining wayleaves in Yorkshire, and also that similar difficulties are encountered in Norway, but the comparison is not a very good one because most of the latter country is undeveloped, and I should imagine that most of the property belongs to the State. I had an opportunity of visiting an electric power station of 3-phase current, 30,000 volts, at Kykkelrud, about 20 miles from Christiania. The points that struck me there were that the poles were of steel trellis about 30 ft. high and about 100 yards apart. Another interesting point was the method of protecting the line from lightning or surgings. I do not know what method of protection is adopted by the Yorkshire Electric Power Company, but in this station they use a water jet which is kept going from a pump and is, I believe, playing within a small distance of the live circuit.

Mr. Yerbury

Mr. H. E. YERBURY: As a tramway engineer I am so greatly interested in the question of overhead line construction that I approve of it and use it myself, but I endeavour to keep other overhead lines outside the zone of our activity. From our point of view telephone and telegraph wires and our guard wires in the vicinity of trolley wires are a constant source of trouble. I have seen the overhead construction in the four countries mentioned in the paper, and I am inclined to think that the veto possessed by local authorities and the regulations of the Board of Trade are not altogether a curse to this country, for we should hardly tolerate in our cities and towns the class of work frequently seen on the Continent. I am in agreement with the author that less stringent regulations are required for the construction of overhead work on, say, pasture or arable land and country roads, and if the general construction conforms to the physical surroundings there should be no cause for complaint from an æsthetic standpoint. The

question of wayleaves, compulsory or otherwise, has always been a troublesome problem, and although, as the author mentions, the Post Office Telegraph Department may now erect their wires on tramway poles, we in Sheffield charge them an annual sum for this concession, because to our sorrow we know what trouble is caused by falling wires during gales or snowstorms. In manufacturing districts power supply would undoubtedly be cheaper if overhead construction were permitted, and I agree with the author that a decision in such matters could very well be determined by the Board of Trade, as they are experts compared with some local authorities. The factor of safety required by the Board of Trade for various wires is, I think, generally satisfactory, and it is to be regretted that the tensile, torsion, and conductivity tests of aluminium compare very unfavourably with copper or bronze wire, but I believe there is a useful field for aluminium, and I intend to experiment with this for negative return cable work. The author has brought forward some useful information regarding poles, etc. Lattice-work poles have always appealed to me, although the question of periodical painting may perhaps make the maintenance cost higher than that of creosoted wooden poles. Mr. Yerbury.

Mr. W. B. WOODHOUSE (*in reply*): A great amount of detail in the past had to be settled by rule of thumb, and this is still the case to a considerable extent. As Mr. Hartnell mentioned, the very serious part of this question is that of the restrictions that we have to fight against. No doubt some means of obtaining compulsory wayleaves would be very much better for our industry and, I think, for the country generally. The question of erecting overhead lines through the centre of towns is another thing altogether. A large town should certainly have a right to say whether they will have these wires in their streets, but one finds objections from small towns as well. They do not fully appreciate that the introduction of what is termed a hideous set of poles may prevent a still more hideous smoking chimney. I have not used glass insulators in the open, as suggested by Professor Parr, my own experience of the use of glass insulators having been for switchboard work, for which they were found to be unsatisfactory. Regarding his remarks as to re-designing them to suit our atmospheric conditions, I think that for outside work the strength and the cheapness of the modern porcelain insulator inclines one to use it. The criticism that Professor Parr makes as to the construction of the insulator illustrated in the paper is, I think, quite justified. The drawing is not quite to scale, and the top shed is actually deeper than shown. Mr. Wright mentioned the conditions that he observed in Norway. Norway is not exceptional, for many districts in South Wales and Yorkshire are just as sparsely inhabited as any part of Norway. It is true that in Switzerland, France, etc., they get compulsory powers without difficulty. As to lightning protection, I think that the experience of the users of overhead lines is that if the lightning strikes the line direct no type of arrester will stop it. It will destroy the nearest points of support but will not carry any considerable Mr. Woodhouse.

Mr. Woodhouse.

distance. We have adopted on our construction a horn arrester. I have tried all types, and I find that they take care of some discharges (probably induced), but none of them will act in every case. One has to take the chance of the line occasionally being struck direct and breaking an insulator. I can quite understand Mr. Yerbury's desire to monopolise the air at Sheffield, but I think that is an argument in favour of compulsory powers. Mr. Yerbury and other engineers think naturally it is very much better for their lines if others are kept away from them. I quite agree that if other engineers' posts are used, way-leaves should be paid and they should bear some relationship to the amount of trouble caused. If one had to take transmission lines a great distance practically in a straight line, I think one would not hesitate to adopt iron and steel poles. In addition to lattice work construction, which is being adopted, the use of reinforced concrete poles is spreading. A good deal may be said for them, and one anticipates that their life will be extremely long as compared with steel or wood, but personally I have no experience of them.

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EXPLANATION OF ABBREVIATIONS.

[P] signifies a reference to the general title or subject of a Paper.

[*p*] signifies a reference to a subject incidentally introduced into a Paper.

[D] signifies a reference to remarks made in a Discussion upon a Paper, of which the general title or subject is quoted.

[*d*] signifies a reference to remarks incidentally introduced into a discussion on a Paper.

Note.—The lists of speakers in the Discussion upon any Paper will be found in the Table of Contents at the beginning of the volume.

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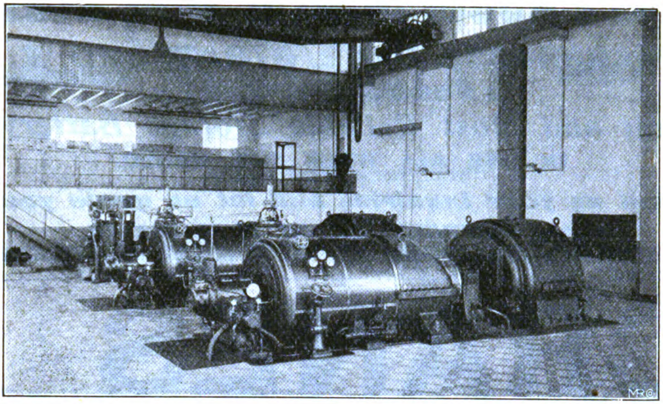

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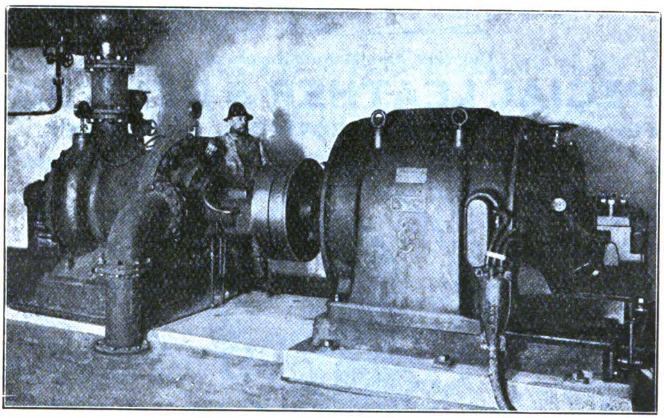

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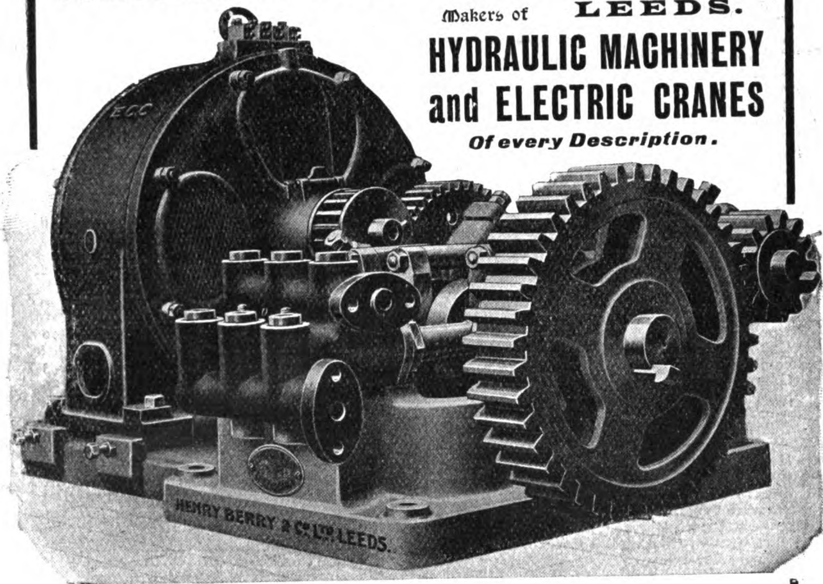

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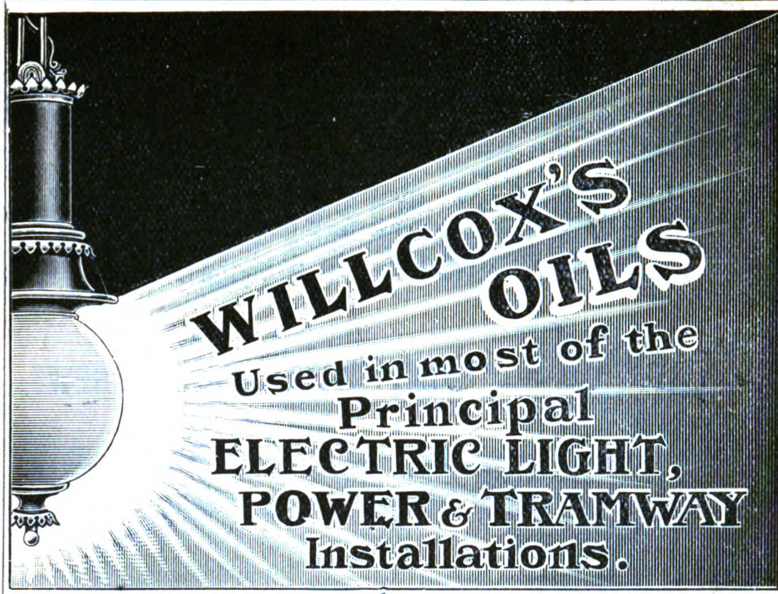

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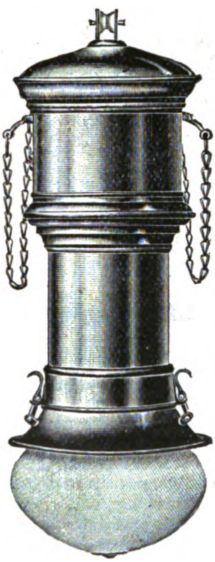

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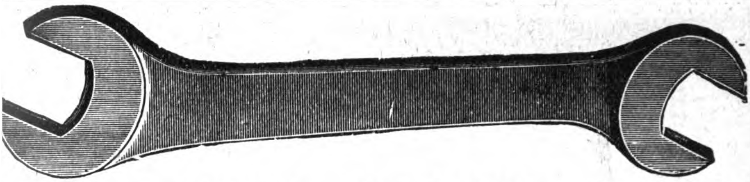

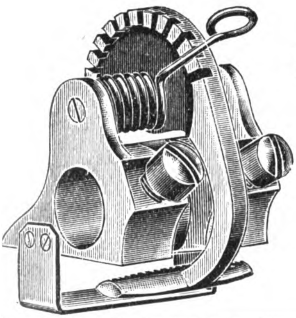

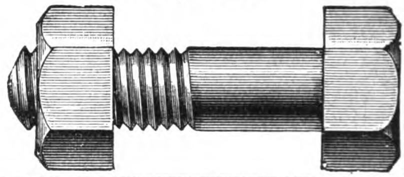

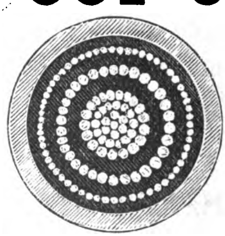

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